The effect of mother plant nutrition on seed yield, quality and vigour in peas (Pisum sativum)

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THE EFFECT OF MOTHER PLANT NUTRITION ON SEED YIELD, QUALITY AND VIGOUR IN PEAS (PISUM SATIVUM)

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Dedication

I would like to dedicate this thesis to my parents, Mehdi and Poran, for providing me with generous moral and financial support.

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ABSTRACT

The effects of mother plant nutrition on seed yield, quality and vigour, in the vining pea (*Pisum sativum* L.) c.v. 'Sprite' have been studied.

In three pot experiments under glass and one field experiment, different levels of nitrogen, phosphorus and potassium were applied to the mother plant. In the glasshouse experiments, increasing the level of nitrogen supplied to the pea plants resulted in increased seed yield, seed nitrogen and hence protein content, and seed size. In two of the three glasshouse experiments, increased nitrogen supply improved seed vigour as determined by seed leachates' conductivity measurements and percentage germination, percentage normal seedlings and seedling dry weight using the standard germination and the cold tests. The effect of phosphorus nutrition on seed yield was not as large as nitrogen, but it improved quality and vigour in seed harvested from all the glasshouse experiments. Increasing the levels of potassium nutrition was found to have no significant effect on seed yield and quality, but significantly affected the number of seeds set per pod.

The interaction effect of nitrogen and phosphorus on seed quality and vigour is more significant than the effect of the individual elements.

Fertilizer application to the seed crop grown in the field failed to produce differences in seed yield, seed chemical composition or seed vigour.

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1. Introduction

Seeds above all else are a way of survival of their species. They are a way by which embryonic life can be almost suspended and then revived to new development even years after the parents are dead. Seeds protect and sustain life. They are also food for man, animals and other living things.

Virtually the whole of man's primitive life was devoted to securing his food supply, at first by hunting and collecting the edible parts of wild plants, and later by planting seeds and harvesting crops. As farming methods improved, it became possible for a man to produce more food than was necessary for himself and his family. From this emerged a social structure in which at its simplest the community was divided into farmers and others, the others obtaining their food from the farmers by barter for goods and services, or by purchase. Today, an efficient agricultural industry is the backbone of a healthy and progressive society.

In modern agriculture the main inputs which affect the agricultural productivity are:

1. Improved seed;
2. Irrigation;
3. Fertilizers;
4. Crop protection;
5. Mechanisation;
6. Careful harvesting
7. Proper storage.

However, further use of inputs such as fertilizers, crop protection chemicals and machinery for increased agricultural production is becoming more difficult because of the rapid increase

in their cost, and at the same time, the demand for food especially in Third World countries is increasing.

It has been shown (Feistritzer, 1975) that those technologies which require the least changes in existing techniques have the best chance of being adopted quickly. It is therefore no great problem to introduce biological technologies to farmers, such as the use of seed of improved quality and adapted cultivars. Thus high quality seed in interaction with other inputs has the genetic ability to increase crop yields substantially. No amount of fertilizer, weeding or careful husbandry will compensate if the seed sown produces plants which are incapable of exploiting the environment in which they have been planted.

In the case of vegetable crop production, apart from the increase in the crop yield, there are further reasons for the need for high quality seeds which make seed production more important. Harrington (1971) points out three reasons: first, the change from hand production has come about only by the development of specialised machines such as precision planters, electronic thinners and mechanical harvesters. Second, the type of vegetable farm is changing from small family operations, where book-keeping is minimal, towards cooperate farming, where profit is essential and the cost of every operation is carefully scrutinised. College-trained growers and staff are aware of the need for high quality seeds and know what factors are involved in quality. And third, the seed business is one of the most competitive in our society, with the competition based on high quality rather than low price.

Because of these points, seed production is an important and fundamental segment of agriculture and the requirements have led to

the recognition of the concepts of seed quality and seed vigour and the detailed study of factors which affect them.

The influence of soil fertility on the quantitative aspect of plant growth is well known, since the production of dry matter by plants is the criterion by which soil fertility is usually assessed. However, little attention has been given to the possible effects of soil fertility and mother plant nutrition on seed quality and seed vigour.

This study was undertaken to investigate the effects of different nitrogen, phosphorus and potassium levels and their interaction on seed yield, quality and vigour of pea *(Pisum sativum* L.), cultivar Sprite, under field and greenhouse conditions.

The relationship between mother plant, mineral nutrition, seed yield and seed vigour by several recognised vigour tests for peas were studied.

1.1 The pea as a crop plant

1.1.1 Origin and Types

The first cultivated plants in the old world were grasses, wheat and barley, but they were soon joined by plants that added valuable supplements to the diet, lentils, peas and vetches, all members of the botanical family Leguminosae (Heiser, 1981). Archeological discoveries of seeds of peas in the early dwellings of man tell us that his history of association with the genus *Pisum sativum* dated at least from the Stone Age times, and probably centres on the land areas impinging on the eastern end of the mediterranean (Pate, 1981).

The modern cultivars have been developed from material originally introduced into Africa, China, Europe and India from South-West Asia. This early distribution over a wide area is believed to be the reason for the present diversity of types. Peas are now widely cultivated in temperate regions and as a cool season crop in the tropics especially at the higher altitudes (George, 1985).

The cultivated pea *(Pisum sativum* L.) comprises two main types of races, the field pea and the garden pea. The field pea includes pigeon and maple peas, of which many cultivars have been developed for different types of animal feeds. The garden pea, with a relatively high sugar content, is considered by some to be the aristocratic food plant of this family. Figure (1) shows the detailed classification of different types of peas by the National Institute of Agricultural Botany, Cambridge (Anon, 1980).

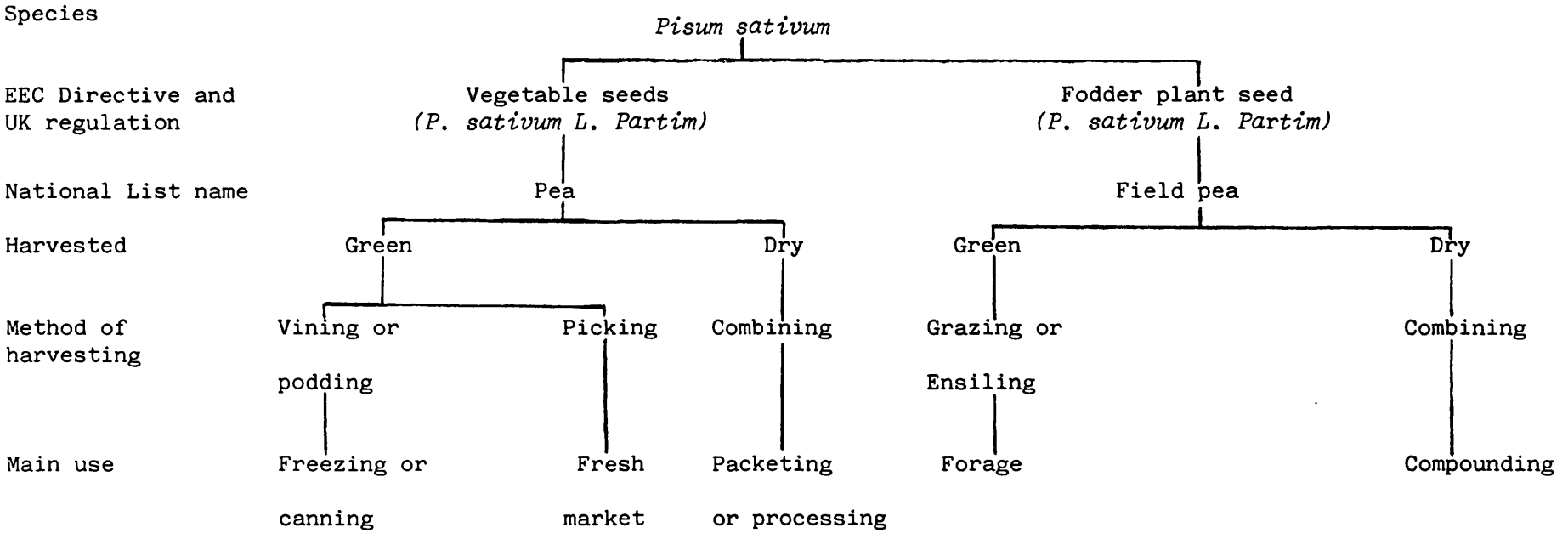

Fig. (1). Classification of peas according to their usage. NIAB (1980).

1.1.2 The development of the pea production industry

Fresh peas were not popular before the seventeenth century, at which time they became esteemed in the court of Louis XIV. For hundreds of years, therefore, the consumption of peas coincided entirely with the fresh pea season, i.e. the summer months, while outside that period, the only peas available were those which had been harvested dry. However, great changes in the economic status of the pea crop have taken place over the last 50 years.

Landmarks in the development were the production of the first pea shelling machine by Madame Faure, which was exhibited at the Paris Exhibition in 1885, successful commercial canning around the turn of the century, and the canning of processed peas in the 1930s. By the 1950s canned garden peas and frozen peas had revolutionized modern eating habits, for they were among the first to be accepted by the housewife and the caterer as an excellent "convenience" vegetable. The production of peas for processing is now considered to be a highly developed, and sophisticated industry, requiring high capital investment in some temperate areas of the world.

The involvement of the processing companies has led to considerable changes in the organisation of the production of the crop. In order to achieve a spread of harvest period when peas are of required quality, some crops are sown much earlier than was usual (Anon, 1980). The efficient processing of vining peas demands constant throughput maximizing the potential of the processing lines with produce of uniform pre-determined quality throughout the greatest possible length of season. Crop production is therefore planned to provide an acceptable load and to fully utilize farm and factory machinery and plant, whereas the efficient production of

dried peas demands early sowing in the interest of yield (Proctor, 1963).

1.1.3 The role of seed in the pea production and processing industry

In each case timing is the over-riding factor, dictating that sowing must often take place when soil and weather conditions are far from ideal. Such a practice presents problems in relation to seed and crop performance, and indeed survival (Gane and Biddle, 1978).

The vining pea crop is precision drilled and the achievement of target populations in the field is important for crop yield and profitability (Gane, 1975). The demands of the processing industry mean that pea crops are often sown in early spring when soil conditions are cold and wet. It is with these early seeded crops that emergence failures are most likely to occur, even when the results from standard laboratory germination tests are satisfactory. Seed which fails in this way is said to be of low vigour. Thus the most important effect of low vigour on pea seeds is failure of seedling establishment, and the associated loss of crop yield. Uniformity in the rate of seedling emergence and plant growth is also important. The harvest time for vining peas has to be accurately determined in relation to the crop's maturity and is a vital factor in determining the quality of the produce. Uneven emergence can lead to lack of crop uniformity at harvest and thus detract from both the overall yield and quality.

2. Literature Review

2.1 Seed quality

In modern agricultural industry, farmers in many countries are under increasing pressure to provide good quality, uniform produce at low cost (Gray, 1983). In order to achieve this, it is essential to have rapid and uniform crop establishment and this in turn requires the use of as high quality seed as possible, because the seed is the starting point in the production of the majority of field crops.

Seed quality is a multiple concept comprising several components, some of major importance,and relates to the suitability of seed for sowing (Thompson, 1979). High quality seed is relatively undamaged, with a high percentage of germination and will produce uniform vigorous seedlings without defects under a range of environmental conditions. Seeds must therefore be evaluated for quality before planting. Germination, purity and health are the three criteria of seed quality which are well established and are determined by routine tests at seed testing laboratories. The results of seed quality tests are of major concern to both the farmer and the seedsman.

To the farmer the seed quality information will enable him to make economic decisions regarding the cost of seeds, earliness of sowing, quantity of seed to sow and anticipated uniformity of crop stand. It is therefore essential for him to use seeds which are of the highest quality possible, in order to reduce the risk on his other investments or inputs such as fertilizers, irrigation, crop protection chemicals, and labour (McDonald, 1977).

To the seedsman seed quality information is useful for devising ways and means of monitoring seed lots during production, harvesting, processing, packaging and storage and determining loss of vigour which precede loss of viability at each stage (Perry, 1973a).

The main characteristics which determine the seed quality are:

i) Genetic quality, i.e. purity of species and purity of cultivar. It is desirable that the farmer should receive the species of seed that he wants and cultivar purity is a measure of the seeds' genetic quality as created by the breeder and maintained by the seed producer.

ii) Purity, i.e. presence or absence of weed seeds and other undesirable by-products. All farm lands contain weed seeds, and when a farmer buys seeds he will not willingly want to pay for more of them.

iii) Physiological quality, i.e. viability, germination and vigour. High germination capacity and vigour enable the seed rate to be reduced.

iv) Health condition; seed health is important in controlling certain crop diseases and in ensuring good field establishment.

v) Morphological quality; the seed must be entire, undamaged and well developed. Sometimes a seed lot can be graded in order to give uniform performance in the field and uniform plants.

vi) Moisture content; moisture content is of interest to the processor and the store manager rather than to the farmer. It is the key factor in determining whether or not seed will retain its germination from harvest to sowing time.
(Wane and McCollum, 1975; Kah, 1974; Harrington, 1971).

Based on the above criteria, seed lots passing the test should be of high quality and emerge reliably in the field, but this is not necessarily so, as the tests are done under 'optimal' conditions and in the field the germination conditions are not usually optimal. The difference between the two abilities of a seed to germinate under optimal and non-optimal conditions is what is called "seed vigour", an important aspect of seed quality in the context of field performance. Although the expression of "seed vigour" has been used for many years,only recently has it been recognised as a definable quality factor and has its effect on the performance of seed and crop in the field been realised (Perry, 1980).

2.2 Seed vigour

With modern agricultural practice of single seed spacing and once-over harvesting of uniformly mature crops, seed quality evaluation particularly seed vigour is becoming increasingly important (Perry, 1973).

The fundamental objective of seed testing is to establish the quality level of seed and to provide the growers with an estimate of the value of the seed for storing.

In recent years, certain phases of seed quality testing have come under attack by seedsmen, agricultural research workers and seed analysts as being inadequate or unrealistic. The two main principal quality factors which are tested for are purity and germination and the criticisms are particularly directed at the germination test. The standard germination test has been criticised because it is done under optimum conditions in the laboratory and optimum conditions are rarely encountered in the field and it is not surprising that field emergence is often less than that predicted by the germination test (McDonald, 1980). He also argued that the germination test fails to take into account the progressive nature of seed deterioration.

It is largely the absence of a consistent relationship between germination in the laboratory and emergence in the field which has been responsible for the development of the concept of seed vigour (Perry, 1973a).

The concept of seed vigour is highly complex. At the biochemical level it involves energy and biosynthetic metabolism, coordination of cellular activities, and transportation and utilization of reserve foods. At the level of seed germination it

involves rate and totality of germination, pushing power of the seedling, range of environmental conditions such as temperature and moisture under which germination will occur and disease resistance. In addition to genetic factors, the cause of low vigour may include environmental conditions during seed development and maturation,such as soil nutrient levels, soil moisture, and light level as well as mechanical damage during harvesting, processing and many others (Anon, 1976). Because of the complexity of factors influencing seed vigour, there is considerable confusion over the definition of the term, which is often used with different meanings by various workers and some even consider it to be unacceptable because it lacks precision (Frank, 1950). Nevertheless, it is generally agreed that there are aspects of seed quality additional to germination capacity which influence field emergence (Frank, 1950).

Most definitions of seed vigour originate from the discrepancy between the germination test result and field emergence. Frank's (1950) proposition that a germination test performed in field soil was in fact a vigour test was based on the different results obtained in soil and artificial substrata.

According to Delouche and Coldwell (1960), seed vigour is generally thought of as 'something' not adequately measured or reflected by the standard germination test. Isely (1957) suggests that two ideas enter into most concepts of vigour, i) vigour per x in terms of rapidity of germination and growth and ii) susceptibility to unfavourable growing conditions. Although these two components could be distinguished as separate entities, they could also be regarded as facets of a single physiological complex, since slow growing small seedlings are often those most susceptible to

unfavourable conditions (Isely, 1957). According to Isely (1957), seed vigour therefore, could be measured in one or two ways, i) by measuring specific physiological attributes such as seedling growth, sometimes referred to as the "indirect test" or ii) by imitating the field conditions referred to as the "direct test". Considerating the above factors, Isely (1957) defined vigour as "the sum total of all seed attributes which favour stand establishment under unfavourable field conditions".

Delouche and Caldwell (1960) criticised the direct method on three accounts, i) it ignores differences in seed responses under favourable conditions; ii) it implies that the low vigour seeds always die whereas in many cases they emerge late and produce low-vigour plants; and iii) it places undue emphasis on the role of microorganisms in germination failure of low-vigour seeds. These authors argue for vigour *per se* (indirect measure), because this places emphasis on the seed and appeared to be the more fundamental concept as a direct expression of physiological and physical conditions of seeds. They modified Isely's definition as follows: "vigour is the sum total of all seed attributes which favour rapid and uniform stand establishment in the field". This definition includes favourable as well as unfavourable field conditions and it also introduces uniformity of stand establishment as a quality factor.

Other definitions of seed vigour relating to direct test methods include Heydecker (1960) and Ader (1965). Heydecker (1960) defines vigour as "the ability to germinate and produce a stand in a suboptimal environment", but later in 1970 (Heydecker, 1970) he suggested that vigour is a scientifically vague term which when

applied to seeds is taken to denote that they are likely to perform particularly well in the field compared with others which may be equally satisfactory in the laboratory tests. Ader (1965) states, "vigour is the percentage of seeds able to produce normally germinating seedlings even though conditions are suboptimal". Neeb (1970) defines vigour or rather one type of vigour, "as the totality of properties contributing to the defence against, and successful resistance to, biotic hazards during germination under suboptimal conditions".

Vigour is viewed in a more positive sense by Nutile (1964) as "the ability of the seed to produce vigorous seedlings as compared to the maximum vigour attainable for the species under similar conditions", and by Woodstock (1969b) as "the condition of active good health and natural robustness in seeds which, upon planting, permits germination to proceed rapidly and to completion under a wide range of environmental conditions". Germ (1960) defines vigour as "the ability of seeds to produce seedlings well capable of increasing in length and volume, while still dependent on their own reserves". Harrison (1966) suggests that the vigour of seedlings can be assessed from the number of anaphases seen per root. Perry (1972) proposes that seed vigour is a physiological property determined by the genotype and modified by the environment, which governs the ability of a seed to produce a seedling rapidly in soil and the extent to which that seed tolerates a range of environmental factors. The influence of seed vigour may persist through the life of the plant and affect yield. Grabe (1973) defined seed vigour as "the actual performance potential of a seed in relation to its genetic potential". The definitions of Woodstock, Perry and Grabe

focus attention on the individual seed and on the fact that the fundamental requirement is that the seeds germinate and do so completely, the quicker the better and the more conditions under which it can do this the better.

Because of the lack of unanimity and the confusion surrounding the definition of vigour amongst the interested parties, the two major seed testing organisations, The International Seed Testing Association (ISTA) and The Association of Official Seed Analysts (AOSA), charged their vigour testing committees with proposing a specific definition for seed vigour.

In June 1979 the AOSA vigour subcommittee proposed the following definition: "Seed vigour comprises these seed properties which determine the potential for rapid uniform emergence and development of normal seedlings under a wide range of field conditions". And in May 1977 (Perry, 1981), the ISTA group proposed the following definition: "Seed vigour is the sum total of those properties of the seed which determine the potential level of activity and performance of the seed or seed lot during germination and seedling emergence" (McDonald, 1980).

The AOSA definition focuses on what seed vigour does and is therefore considered to be an "operational" definition, whereas the ISTA definition is considered to be "academic" beause it discusses, identifies and describes seed vigour and the ISTA definition goes on to describe four broad areas where these may be observed. These are

1. biochemical processes and reactions during germination such as enzyme and respiratory activities;
2. rate of uniformity of seed germination and seedling growth;

3. rate of uniformity of seedling emergence and growth in the field;
4. emergence ability of seedlings under favourable environmental conditions.

(Perry, 1981).

The ISTA Committee outlines a list of major factors which can cause changes in the level of seed vigour. They are:

1. the genetic constitution of seed;
2. environment and nutrition of the mother plant;
3. stage of maturity at harvest;
4. seed size, weight or specific gravity;
5. mechanical integrity;
6. deterioration and ageing;

and 7. pathogens.

The Committee also reports that seed dormancy may obscure vigour potential of the seed lot in a laboratory test but it should not be regarded as a component of vigour if seedling emergence is unaffected in field sowing.

The ISTA Vigour Test Committee's definition of vigour has not been fully accepted. Ellis and Robert (1980) argue that the seed vigour remains a vague qualitative concept because if this definition is accepted it cannot be measured for the following reasons: i) there is no list of the properties referred to and there is no way of knowing when any list is complete, ii) some of the properties which have been claimed to be important such as integrity of cell membranes, rate of germination and various types of synthetic activity are all measured by different units and therefore cannot be added to produce a "sum total" except in a very arbitrary fashion,

iii) it is not clear what is meant either by "activity" or "performance" of a seed or seed lot, iv) even if activity and performance were defined, their expression would undoubtedly depend on environmental conditions during "germination" and "seedling emergence" and these conditions are not defined; and v) "seedling emergence" presumably refers to emergence in the field, where environment cannot be controlled or predicted and can be described only in part and then only retrospectively.

2.3 Tests for seed vigour

2.3.1 Review

Assessing seed vigour has become an increasingly important aspect of seed testing, since increased emphasis is put on the seed vigour. The objectives of seed testing are to provide the grower with an estimate of the value of seed for planting and to give an impartial guarantee of quality in commercial transactions (Perry, 1981).

Many tests have been proposed and they have been reviewed by different workers (Heydecker, 1969; Isley, 1957; Moore, 1968; McDonald, 1975). Some of them classify the vigour tests into three groups:

1. Physical tests, which measure seed characteristics, e.g. size, weight and density.
2. Physiological tests, which use some parameters of germination or growth.
3. Biochemical tests, which investigate reactions involved in cellular maintenance.

The Vigour Test Committee (Perry, 1978) gives the definition of the vigour test and its principles. According to this Committee, "the vigour test is a reproducible laboratory method which distinguishes seeds of different levels of vigour". Furthermore, a vigour test "... must have been proved to be correlated with a field performance characteristic such as seedling emergence under environmental stress".

The same Committee divides the possible vigour tests into two categories as follows:

1. Direct tests; in which an environmental stress in the field is reproduced in the laboratory, e.g. Hiltner test, cold test.
2. Indirect tests; within recent years considerable research has been directed towards the development of vigour tests of the indirect type.

Some of the simplest means of estimating vigour indirectly are by measuring the seeds' physical characteristics. For lettuce, seed weight was found to be more important than seed width or thickness in predicting vigour. Smith *et al.* (1973) and Scaife and Jones (1976) showed a linear relationship between seed weight and emergence and yield in lettuce.

Perry (1981) describes the indirect tests as those in which a seed characteristic measured in the laboratory is related to performance in the field. One of the earliest indirect tests was a measurement of the rate of germination which could be estimated by a first count in the germination test. Rate of seedling growth has also been used and frequently is estimated by measuring seedlings after a specified period. The conductivity test for peas *(Pisum sativum)* is also an indirect test in which the quantity of electrolytes leached into water during a 24 h soak is correlated with emergence. Similarly, the proportion of seeds surviving treatment at high temperature and moisture content, which induces rapid deterioration, may also be correlated with emergence. Finally, immersing seeds in tetrazolium chloride solution reveals the presence of dead tissue, the location and extent of which are related to sowing value.

The following is a concise summary and description of each of these tests.

2.3.2 Methods

2.3.2.1 Hiltner test

This test was developed originally by Hiltner and Ihssen (1911) for detecting seed-borne infection by *Fusarium* spp. when it was observed that coleoptiles from infected, germinated seeds were short and not able to penetrate a 3 cm thick layer of brick grit without visible damage. They recommended that the test should be done at room temperature in the dark, to provide conditions which favoured development of the fungi and increased the amount of visible damage on the seedling. Modifications of the test with varying temperatures have been suggested as techniques for detecting *Fusarium* spp. (Neergard, 1977). Because of difficulties in obtaining brick grit or because it was not suitable for some crops, other media have been used, for example olochite (Perry, 1969). Many reports show that the test can detect seed samples with low vigour caused by microorganisms or by other factors, more reliably than the standard germination test. The disadvantages of this method are high costs, difficulties with supply of brick grit, large space, long duration requirement and the lack of distinction between effects of pathogens and physical causes.

2.3.2.2 Cold test

Perhaps the most widely used vigour test is the cold test, which imposes stress on germinating seedlings by subjecting them to microorganisms and to a cool moist soil environment. The theory

behind the mechanism of the cold test is that the cold, wet, soil conditions slow down the activity of both the seeds and soil micro-organisms. The seeds, however, are at a relatively greater disadvantage, making them susceptible to attack by the decay organisms claims Leach (1947). Vigorous seeds and seedlings are then able to resist the decay organisms to a greater extent than weaker seeds (Grabe, 1976).

The cold test is essentially a germination test started in cold soil and completed in relatively warm soil. Early work at Iowa State University led to its development as a routine test for corn *(Zea mays)* and others have helped to refine it (Isely, 1950).

Cold testing of commercial seed was used by the pioneer Hi-bred seed company in the early 1940s. Today it is widely used by commercial seed companies, certification agencies, and experimental stations for evaluating seedling vigour in corn and to some extent to soya beans in the USA. Although its major use is to determine emergence potential and performance weaknesses in seed lots, it is also used to determine the effectiveness of fungicide treatment, seed storability and to evaluate inbred lines of corn used in breeding for resistance to seed rotting fungi.

According to Woodstock (1976), the ability of seeds to germinate in cold, wet, soil is affected by heredity, mechanical injury, seed treatment and physiological condition of the seeds. The cold test measures the combined effect of all these factors and probably other factors and therefore it is not strictly a test of seed vigour but rather a test of germination performance under the conditions provided. When the figures for potential germination from the cold test are very close to those obtained in the standard

laboratory test, the seed lot invoved would be expected to germinate relatively well over a wide range of soil moisture and temperature conditions. However this test has been criticised because the soil conditions (including the microorganism content, temperature, moisture and pH) are difficult to reproduce.

In this study, an attempt was made to use the cold test to estimate the vigour of pea seeds obtained from plants grown under different nutrient treatments.

2.3.2.3 Rate of germination

This test has been suggested as a vigour test because vigorous seeds have been shown to germinate rapidly. Various techniques have been used to measure rate of germination. Stahl (1931, 1936) defined germination rate as the percentage germination at the first count. In a number of comparative tests he showed that the routine germination test was not dependable as a measure of the plant-producing power of seed samples under field conditions. For a number of years first counts were regarded as useful criteria for judging vigour and were included on 'International Analysts Certificates'. Tucker and Wright (1965) developed a regression index where the number of days required for 50% germination was recorded.

Rate of germination tests have the advantage of being inexpensive, rapid, require no specialised equipment and do not necessitate additional technological training of seed analysts. This method has been criticised because variables such as moisture and temperature are difficult to standardize among laboratories, yet they have a profound effect upon the rate of germination. It requires the analyst to have a well defined concept of a germinated seed and

germination must be detected at the earliest possible moment. For those seeds which are dormant, this type of test would be unacceptable.

2.3.2.4 The standard germination test

This test has been shown to be a reliable vigour test under optimum field conditions. It has the same advantages and disadvantages as the rate of germination test indicated above. AOSA rules (1954) define laboratory germination: "In seed laboratory practice, germination is defined as the emergence and development from a seed embryo those essential structures which for the kind of seed in question, are indicative of the ability to produce a normal plant under favourable conditions". It has been further remarked that testing under field conditions or similar conditions is usually unsatisfactory as the results of such tests cannot be duplicated with reliability. Thus, germination tests must be carried out under favourable laboratory conditions which will permit reproducible results.

The germination tests have been criticised in that they do not adequately evaluate the stand-producing potential of seed. The more favourable the germination condition, the greater is the contribution of weak, non-vigorous seeds to the germination percentage. The realisation that the germination test was inadequate to predict field emergence in most crops under adverse field conditions emphasised further investigation for a more appropriate vigour measurement.

In this study, this test was used as a basis of a comparison for the other vigour tests.

2.3.2.5 Controlled deterioration test

This method was developed by Matthews (1980). Two lines of research helped in the formulation of this method. The proportion of seeds surviving treatment at high temperature and relative humidity which induces rapid deterioration has been shown to be correlated with emergence. Delouche and Baskin (1973) found that the germination responses of seeds after a short period (days) at high temperature (40 - 45°C) and high relative humidity (100%) were highly correlated with responses in storage under a range of conditions for periods up to 3 years. This technique was called accelerated ageing since the ageing process occurred within days. The germination of soya bean after accelerated ageing was also shown to relate closely to field emergence (Delouche, 1973), suggesting that accelerated ageing could be adopted as a vigour test for predicting field emergence.

The second research line was that of Roberts (1973), who demonstrated for several species the precise nature of the relationship between the decline rate of viability and the moisture content and temperature at which seeds are stored. This suggested that outcome of storage at a particular seed moisture content and temperature would be highly repeatable for any one lot. Furthermore, precise control over seed moisture and temperature would enable comparison of the deterioration of several lots to rank them in an order that would be the same each time the comparison was made.

Delouche and Baskin's method has been criticised in that it is difficult to apply identical conditions to all seed lots because the initial moisture content may be different in different seed lots before applying the accelerated ageing treatment and thus the precise

nature of the comparison of response to deterioration is lost. The method finally adopted by Matthews (1980), compares the germination of seed lots after closely controlled deterioration at known seed moisture and temperature. In this method, as described by Matthews, a seed sample is weighed and its moisture content is determined by the internationally recommended procedures (Anon, 1976). The seed is then placed on a moist seed test filter paper and allowed to imbibe to the required moisture content. The attainment of this moisture level is checked by frequent weighing. The partially imbibed seeds are then held in a sealed container overnight at 10°C to ensure an even distribution of moisture and the sample is incubated in a water bath at 45°C for 24 hours. The seeds are then set to germinate at 20°C on a moist seed circle. Counts of germination are made every few days until no more germination is seen. A seed is regarded as germinating when its radicle appears. Matthews (1980) suggests that a moisture content of around 20% seems to be suitable for testing a number of crops, such as turnip, swede, kale, cabbage, cauliflower, sprouts, sugar beet, carrot, lettuce and onion.

2.3.2.6 Electrical conductivity

In wrinkle-seeded peas, the field emergence of seed lots and the units in which seeds are produced, tested and sold, can be highly variable, even with one cultivar (Perry, 1967), and emergence has been negatively correlated with the readiness with which electrolytes and sugars can be leached from the seeds into water (Matthews and Whitbread, 1968). Seed lots from which solutes are readily leached, emerge poorly in the field and failure to emerge has been associated with infection by the soilborne fungus *Pythium*

ultimum (Matthews and Whitbread, 1968). Perry (1973) showed a significant negative correlation between susceptibility to *Pythium ultimum* T. and field emergence in seed lots of peas and suggested that imperfections in the testa had an important influence on susceptibility to infection.

Matthews and Bradnock (1967) developed a test where the electrical conductivity of water in which seeds have been steeped is related to their emergence in the field. Perry (1970) found that the field emergence of peas is related to the conductivity of leachates from seeds. More electrolytes were exuded from dead and low vigour seeds than from high vigour seeds in peas (Perry and Harrison, 1973).

According to Woodstock (1973), the leakage of metabolites from seed tissue could be inversely associated with seed vigour on the basis of three factors. Firstly it reflects a loss of membrane integrity, secondly a loss of essential cell constituent and thirdly, it serves to attract microorganisms. There have been many theories developed in order to explain the mechanism of leaching.

Differences in leaching in viable and healthy seeds may be due to differences in physical conditions of seed coat. Perry (1973) showed that seeds with microscopic cracks in the testa revealed by Fast Green dye, produced higher conductivity readings than seeds without this structural defect. Biddle (1980) also showed seed coat cracks to be associated with high electrical conductivity and are consequently believed to be an important cause of low vigour in wrinkle seeded vining pea seeds. Biddle also suggested that seed coat cracks occur during the thrashing operation and it would follow that any post harvest mishandling of seed is likely to aggravate the

problem. Despite the experimental limitations, he also found from the results and observations reported elsewhere that the degree of seed coat cracking could well increase with decreasing level of moisture content of the seed.

Matthews and Rogerson (1976) reported that for all the seed lots of pea examined, testa was found to be a barrier to the loss of electrolytes. However the major source of differences in the levels of leaching found between seed lots arose from differences in the condition of the embryos and not in the ability of embryos to retain solutes was the important characteristic determining leaching and seed vigour, probably due to impairment of membrane functioning in leaky seeds.

Simon and Raja-Harun (1972) also developed a theory to explain the mechanism of leaching. The fact that leakage is most rapid a few minutes after the start of imbibition and then declines steadily, was used as evidence that cell membranes require some time after hydration to re-establish their molecular structure and develop their semi-permeable characteristics.

Evidence of structural disorganisation and loss of integrity of the tonoplast and plasmalemma in the mature seed was provided by an electron microscope study of the developing pea by Bain and Mercer (1966). This hypothesis is also supported by evidence from biophysical studies of membranes and phospholipids, which indicate that at water contents below about 20% of their dry weight they lose their structure and become porous (Simon, 1974). Thus the state of cell hydration determines membrane structure and extent of leakage. Indeed, it is only when dry seeds of less than approximately 30%

water content are imbibed that leaching occurs (Simon and Weibe, 1975).

An alternative explanation for rapid early leakage from pea embryos was put forward by Larson (1968) who suggested that the removal of the seed coat resulted in excessively rapid imbibition which caused damage to cell membranes and consequently greater solute loss. Powell and Matthews (1978) provided evidence in support of this hypothesis. They demonstrated that cell death occurred on the abaxial surface of cotyledons in seeds where the rate of imbibition was rapid. They concluded that both cell damage during imbibition and loss of membrane structure in dry seed may be the underlying causes of solute leaching.

Browning (1980) concluded in her review that the result of the electrical conductivity test depends on all of the following seed characteristics: seed viability, embryo damage, testa integrity and the physiological condition of the cotyledonary cells. It is probably because the test has such a broad basis that it has correlated so well with field emergence in peas.

2.3.2.7 Hollow heart

Another pea seed characteristic which has been found to be an important determinant of seed vigour is the condition known as hollow heart. This develops during seed germination and is visible as a cracked, shrunken and sometimes discoloured area on the adaxial surface of the cotyledons (Myers, 1948). It is a common condition of pea seeds, and in some lots up to 60% of the sample was found to be affected (Perry, 1967a). The degree of hollow heart detected can depend on the conditions used for assessing it (Heydecker and

Kohistani, 1969). Generally, seeds are soaked for twenty-four hours and germinated in sterile conditions for several days after which time the cotyledons are split open and the incidence of hollow heart recorded.

The cells of the concavity are thought to be dead although tetrazolium staining has not provided conclusive evidence of this (Perry and Howell, 1965; Heydecker, 1968; SIngh, 1974). Death could occur during seed maturation or more probably as a direct result of the imbibition process (Perry and Harrison, 1973).

The lack of consistent relationship between incidence of hollow heart and electrical conductivity of seed lots has frequently been noted (PGRO, 1971; Harrison, 1972; Scott and Close, 1976). Normal and hollow heart affected seeds cannot be distinguished by their leaching characteristics (Gane and biddle, 1973). Seedlings which exhibit hollow heart symptoms are weak and often fail to emerge in the field. Those that do,produce smaller plants and lower yields (Harrison and Perry, 1973). There is therefore,need to assess seed lots both for hollow heart and for their performance in the electrical conductivity test, in order to obtain a more reliable guide to field planting value.

2.3.2.8 Tetrazolium test

The tetrazolium (TZ) test relies upon the action of dehydrogenase enzymes. It was used to test seed viability first by Iakon (1942) and since then it has been employed on many different crop seeds as a rapid germination test. The preparation and staining techniques are described in the Rules for Seed Testing (Anon, 1976). The indicator used in this test is a colourless solution of the

tetrazolium salt which is imbibed by the seed. Within the seed tissues it reacts with hydrogen atoms released by the hydrogenazes and as a red stable and non diffusible substance (formazan) is produced in living cells, while in dead cells no reaction takes place and they remain colourless. This makes it possible to distinguish the red-coloured living parts of seeds from the colourless dead ones.

This method has the advantage in that it can be performed rapidly, requires no elaborate equipment and is particularly useful when seeds are dormant (Perry, 1981). This method has been criticised in that technicians need considerable training in TZ staining and embryo morphology in order to ascertain from topographical staining whether or not a seed is vigorous. It requires constant supervision and standardization.

2.3.2.9 Adenosine triphosphate (ATP) content and seed vigour

The expression of seed vigour is influenced by three sets of interacting components, resulting from a) genetic makeup; b) seed development, harvest and storage conditions, and c) seed germinating environment. What these components are precisely involved in, in terms of physiological processes, biochemical systems and functional structures are being explored by research workers around the world (Ching, 1982).

In general, a high seed germination rate and rapid seedling growth are accompanied by high anabolic enzyme activity, respiration, ATP, pod size, and the synthesis of proteins, RNA and DNA. Therefore, there have been attempts by research workers to find a biochemical index with which seedling vigour can be quickly measured

without the complications of growing conditions and the required long growing period.

The energy status of seeds during formation, storage and germination can be used as an important expression of seed vigour in terms of the rate of germination and the rate of seedling growth. In general the higher the energy status, the more and faster the growth. In recent years, significant correlations have been found between ATP and vigour in lettuce, ryegrass and crimson clover seeds (Ching, 1982).

ATP is the biological energy needed for every biosynthetic pathway as well as biological work, e.g. movement, transport, assembly of organelles, and repairs. The ribonucleotide is one of the components of RNA and DNA. Upon reduction via nucleotide reductase to deoxyribonucleotide, it becomes a component of DNA. Thus ATP plays a regulatory role in biosynthesis of growth (Henderson and Paterson, 1973; Atkinson, 1977). In embryonic, meristemic or growing tissue, ATP synthesis, utilization, and regeneration are rapid. During seed formation ATP content and energy charge of seed increases in concert with the biosynthetic needs for structural growth, cellular enzymes and organelles in the early stages and for food reserves at the later stages (Ching, 1974). During germination, the embryonic axis of a seed has the enzymes, the substrates, and the factors for *de novo* synthesis of ATP (Brown, 1965; Pradet, 1968; Ching, 1972; Anderson, 1979).

In this study, the following vigour tests were used to determine the vigour of the seeds produced under different nutrient regimes in the experiments in addition to the standard germination

test; i) seedling evaluation test,ii) cold test, iii) electrical conductivity test, and iv) the ATP measurement. The materials and methods for each of these tests are described in Section 3.3.

2.4 Causes of low vigour in peas

Low vigour in wrinkle-seeded vining peas has been associated with two distinct conditions; hollow heart (Myers, 1948) and the loss of leachates when seeds are steeped in deionized water (Matthews and Bradnock, 1967).

Myers (1948) described hollow heart as an abnormal condition of garden pea seed, characterised by the presence of sunken areas in the cotyledons of germinating seeds. Known also as cavitation, the condition becomes apparent during germination as a more or less hemispherical region of dead cells in the centre of the cotyledons (Heydecker and Feast, 1969). Investigations by Perry and Howell (1965) have shown that hollow heart is a common disorder of wrinkled seeded peas which can be found in a high proportion of seeds in some samples and is not confined to any particular cultivars.

Heydecker and Feast (1969) showed that the hollow heart condition developed during seed maturation but the specific cause was not determined. Perry and Howell (1965) attributed the inherent cause of this condition to rapid drying of pea seeds prior to maturity, and the evidence that the cells died during germination suggests some form of predisposition. They did not find any pathogen associated with the condition and a mineral deficiency was not considered to be the cause.

Another cause of poor establishment was found to be seed coat injury. Powell and Matthews (1979 b) demonstrated a relationship between seed coat injury and leakage of electrolytes when seeds were steeped in deionized water. The seed coat cracks were associated with areas of dead cotyledon tissue, increasing electrolyte leaching. Larson (1968) suggested that the high level of leakage

from dry pea seeds was due to sudden and rapid imbibition causing damage to the cell membranes of the cotyledon. The damage observed after imbibition in water (imbibition damage) is eliminated when the rate of water uptake is slowed down and the sensitivity of embryos to imbibition damage is increased at low temperatures (Powell and Matthews, 1979). The presence of seed coat cracks is therefore considered to be an important factor associated with low vigour in pea seeds (Powell and Matthews, 1979).

Results of work by Biddle (1980) indicated that pea cultivars differ in their reaction to seed-coat cracking. The majority of pea seeds sown in the UK is produced overseas, especially in the U.S.A., Hungary and New Zealand and the climate of those seed producing countries results in seeds which are harvested at moisture contents in the range of 10-15 per cent. Seed coat injury may well be incurred more readily at these lower moisture contents. Biddle's experiments showed that seed-coat damage was incurred during the threshing operation and that the number of seeds with cracks increased as the moisture content decreased (Biddle, 1979).

A negative correlation between the level of seed exudates in deionized water and percentage seedling emergence in unsterilised soil has been reported for seed samples of peas by Matthews and Bradnock (1967). As differences in exudation were found between samples of one cultivar, it was suggested that samples may differ not only on genetical differences between cultivars but also because of some aspect of their production, handling or storage (Matthews and Bradnock, 1968).

Commercial seed sold in the UK is produced in several parts of the world, so differences in climate, and in growing techniques in,

and their efects on, different cultivars may be reflected in variation in seed quality (Bedford, 1974).

Excessive rainfall at harvest time is a well known cause of relatively poor seed quality, since it creates conditions which promote fungal activity and seed infection (Flentye, 1964; Matthews, 1973b). Cycles of wetting and drying can cause swelling and contraction of the seed, setting up physical stresses which result in microscopic cracks in the testa (Perry, 1973). High humidity and high temperatures during seed maturation is a cause of seed bleaching and the associated loss of vigour (Maguire *et al.*, 1973; Short *et al.*, 1977).

Biddle and King (1978) showed that harvesting seeds at moisture contents of higher than 35 per cent by conventional cutting and threshing procedures resulted in low germination, low vigour and a high proportion of immature seeds. However, both desiccating the crop at 40 percent moisture content, cutting at this stage and allowing drying to take place in wind rows produced seeds of good quality. They also detected an improvement in seed quality when crops were harvested by cutting and vining between 30 and 35 percent moisture content but some deterioration in seed quality occurred in crops left until full maturity when the moisture content was below 25 percent.

Good storage conditions are important for maintenance of high seed vigour. Powell and Matthews (1977 , 1978) indicate that an adverse warehouse storage environment can be a cause of low vigour in peas.

Thus there are several aspects of the mother plant's environment which have been shown to affect pea seed vigour. The next

section deals with the effects of nutritional environment, the main topic of this research project.

2.5 Effects of mother plant nutrition on seed yield, quality and progeny performance

Application of the correct level of fertilizers is necessary to achieve maximum yield of crops. In addition for seed crops the effect of fertilizer levels on seed nutrient content is also important. Inorganic nutrients stored in the seed provide valuable reserves during the early germination stages, which can be especially critical in soils that are low in nutrients.

The following is a review of some of the literature investigating the effect of mother plant nutrition on seed yield and quality of some agricultural and horticultural crops.

Croker and Barton (1975) stated that seed yield and quality are considered as separate entities. It is not sufficient to simply provide the essentials for good vegetative growth, as production of good quality seed does not always accompany good vegetative growth. It is desirable to know whether certain nutrients will increase or decrease the yield and quality of seed.

Today there is common agreement that mineral nutrition of the mother plant affects seed quality (Perry, 1972; Pollock and Ross, 1972; Copeland, 1976; Perry, 1978; Gray *et al.*, 1982). Provided with the I.S.T.A. definition of seed vigour (1978b) is a list of the major factors which may cause variation in vigour. The environment and nutrition of the mother plant is included among these factors.

The first investigated effects of mother plant mineral nutrition were the effects of the plant's nutrient deficiency on seed performance. Harris (1912) investigated three pure lines of french bean *(Phaseolus vulgaris)* grown in two fields, one described as fertile and the other as infertile. The fields subsequently

received similar cultivation and produced seed crops with differences in growth, but Harris did not suggest if these differences were due to lack of any specific nutrients. Seeds from plants produced in both fertile and infertile fields were sown in a "comparison field". The seeds from the infertile field gave plants with slightly, but consistently fewer pods per plant than those from the fertile field.

Also, among the early investigations concerning the effects of mother plant nutrition and seed quality, are Claypool (1932), Fox and Albrecht (1957) and Iwata and Egui (1958).

Claypool (1932) studied the effects of mineral nutrition and farmyard manure on seed yield, size and thousand seed weight of lettuce *(Lactuca sativa* L.). He found that for seed yield and size nitrogen was the main factor. Phosphorus was the second limiting factor, while potassium had no apparent benefit in seed development.

In a study on the effect of phosphorus and nitrogen fertilizers on wheat seed quality by Fox and Albrecht (1957), particular attention was given to the relationship between soil and climatic factors, fertilizer application, seed yield, seed composition, seed size, field emergence and germination percentage. Both nitrogen and phosphorus had a beneficial effect on seed quality, but results differed according to trial location. There is evidence that during a favourable year seedling emergence was improved when nitrogen content of the seed increased, but this did not happen during an unfavourable year. Moderate amounts of phosphorus improved seedling emergence but large quantities depressed it. Browning (1980) made the following two general conclusions ;

firstly that high seed yield may not be used as a guide to seed

quality and secondly, the importance of the interaction between nitrogen and phosphorus in producing a balanced nutrient regime, which is required for high quality seed, must be stressed.

Iwata and Eguchi (1958) used sand culture techniques to investigate the effects of limiting the phosphorus and potassium supply at various stages of growth in a seed crop of Chinese cabbage *(Brassica campestris* L. *Chinensis)*. Withholding phosphorus at any stage up to early flowering reduced seed yield, seed size, seed phosphorus content and resulted in seedlings with slower rates of radicle growth. In contrast, the limitation of potassium supply had no effect on seed size, seed potassium content or radicle growth rates, even in treatments where seed yield was much reduced and the plants showed signs of potassium deficiency. The nitrogen nutrition of cabbage and Chinese cabbage was investigated in the field, in a more typical crop production situation (Euguchi, 1960). Application of nitrogen during the reproductive stage of crop growth primarily affected seed yield by increasing the numbers of secondary inflorescences and had no effect on seed germination percentage or 1000-grain weight.

Subsequent studies have been made by different workers attempting to explain the effects of mineral elements on seed production. Nitrogen, phosphorus and potassium have been the main nutrients examined and in addition some of the micronutrients, each one separately or in combination with others. Nitrogen and phosphorus seem to play the most important role in seed production and development, but there are two main groups of opinion as to the effects of each. According to one, phosphorus is the most vital element for the seeds, since seeds with high phosphorus content

perform better in the field. The other group considers that nitrogen is the most important element for seed production, because it is mainly responsible for the increase of seed protein, which is one of the most important reserve foods for the young seedlings (Gauras, 1981).

The work concerning the nitrogen effects on seed production and seed performance and its relationship with the seed protein has been mainly done with cereals. Because of its relevance to the present discussion it merits inclusion.

Increases in seed protein content due to nitrogen application have been reported for many species and in some cases it has been claimed that such an increase can lead to improved seed vigour, though not necessarily improve germination. Protein is the major nitrogenous reserve material in seeds but there are numerous different proteins in various parts of the seed, but are mainly found in the endosperm in cereals and in the cotyledons in legume seed. Final protein content depends on many factors, including the availability of nitrogenous fertilizers, and the timing of application is important in this respect. In cereals, early application can increase overall yield, but not the amount of protein per grain, whereas late applications of nitrogen can increase grain protein considerably. The demand for nitrogen by the plant in order to increase seed protein is very high as demonstrated by Bhatia and Rabson (1976), who showed in a range of cereal species that each 1 percent increase in grain protein required an increase of between 6 and 11 percent nitrogen.

A group of scientists working with Ries, have completed a comprehensive investigation on the effect of nitrogen nutrition on

wheat seed performance. Preliminary work with wheat and oats by Schweizer and Ries (1969) showed that increasing the protein content of seeds, either through increased nitrogen supply or by application of sub-lethal doses of chemical herbicides such as simazine, atrazine and terbacil, resulted in seedlings with increased vigour. Both seedling fresh weight and seed yield in the next generation were increased in the high protein seeds.

Ries *et al.* (1970) recommended foliar application of N as a means of improving wheat seed protein and seed yield. In similar work with wheat, Lopez and Grabe (1973) obtained different N contents of seed from different rates of N application to the mother plant. High N tended to increase N content, but decreased seed size. Also, the rate of water absorption and oxygen consumption of a germinating seed increased with increasing N content and this resulted in faster germination and larger seedlings, especially when grown in N deficient soil. Similarly, Holzman (1974) demonstrated that in the laboratory, seeds with high protein content produced taller and heavier seedlings than those of low protein content, but in a pot experiment produced no yield advantage.

Ries and Everson (1973) studied the relative contribution of genotype and environment in determining wheat seed N and seed size and related these effects to seedling vigour. Their results indicated that both environment and genotype affected the N content of the seeds. Regardless of genotype or environment, seedling vigour was also related to seed size but when uniform seeds were used, the seed N content and vigour relationship was significant. It can therefore be said for wheat that the general trend is for N

fertilization to directly affect N content of seeds which is an important factor governing seedling performance.

Harrington (1960) working with various species (carrot, lettuce and pepper) grown under severe nitrogen deficiency, found that deficient plants gave very low yields of seed compared to those from control plants and much of the seed was abnormal. The percentage germination of normal seed from the deficient and control plants was normal.

Positive correlations between nitrogen nutrition and seed quality (i.e. germination) have been reported for lettuce (Soffer and Smith, 1974), tobacco (Thomas and Raper, 1979), sugar beet (Pendleton, 1954), tomato (George *et al.*, 1980), bean seed (Ries, 1971), and French bean (Gavras, 1981).

Gavras (1981) studied the effect of mother plant nutrition on French bean (*Phaseolus vulgaris* L.) seed yield, quality and progeny performance. He found that higher yields were obtained with higher nutrient levels tested, but the high seed yields were not generally accompanied by high seed quality. N and K increased both seed yield and quality but P increased seed yield and decreased seed quality. Liaw (1982), also working with French beans showed that higher hundred-seed weight was produced by low application of nitrogen, but high application of phosphorus increased the hundred-seed weight. High levels of nitrogen produced seeds which were more vigorous with a lower conductivity reading and gave better seedling emergence with the cold test.

Ahmed (1982) found that with onion, under greenhouse conditions, nitrogen up to medium level (2400 mg/plant) increased seed yield, but phosphorus and potash had no significant effect

except in combination with nitrogen. The seed yield increase was accompanied by reduction in seed quality. In the field crop of onion he found that neither level of nitrogen or time of application had any effect on seed yield, but low nitrogen level especially at flowering time, improved the seed quality.

In a radish crop, Singh and Cheema (1972) applied 100 and 200 kg of N and 50 and 100 kg of P per hectare, along with different levels of irrigation. Higher doses of N (200 kg/ha) had significant seed yield increase over low dose. Higher doses of nitrogen also increased the 1000-seed weight and 'A' grade seeds over lower dose but had no effect on seed germination.

Phosphorus (P) is found in nucleic acids, nucleotides and phospholipids and also plays a vital role in plant metabolism. This element is important for the development and growth of roots, particularly in the early stages of plant life (Flegmann and George 1975). Phosphorus has therefore always been considered as an essential element for the formation of the inherent parts of cells and as seeds consist of cells as units, P must be necessary for the formation of new seed.

In their work on the relationship between P nutrition and tomato seed production, Anisimov and Popova (1954) reported that seeds from plants receiving high levels of P produced larger seedlings and at crop maturity the plants bore increased yields of fruit. A difference was also detected in fruit quality, with fruits from the higher yielding plants having a higher sugar and vitamin C content and a reduced acid content.

The importance of P on flax and rape seed has been investigated by Szukalski (1961). In pot experiments, he

applied different levels of P before and after sowing, including post-emergence. As a result, seeds were obtained with a different percentage of P content. The influence of the P content in the seed upon the yields was investigated in pot experiments in pure quartz sand in soil. Seeds with higher P concentration, sown in soil which was low in P, germinated faster and uniformly, produced plants which flowered earlier, had a better growth at the beginning of vegetative period and a higher final yield. But in soils high in P, these differences in growth were observed in the beginning, but not in the final yield.

Lipsett (1964) working with wheat, reported that P concentration in the seed is important for the seed performance. He collected 20 representative samples of wheat containing an average of only 0.35 percent of P from P deficient sites in Australia. In pot experiments, the wheat grain P concentration increased to 0.45 percent by applications equivalent to 150 kg P_2O_5/ha. He noted that cultivars responded differently in their behaviour in deficient soil, some giving more grains per ear with a lower P concentration than others.

Austin (1966a) working with watercress, found that seed harvested from P deficient plants had a slower rate of germination and a lower final germination than the seed from the normal plants.

Additional evidence for the important role of seed P was presented in an experiment on different manurial treatments of carrots (Austin and Longden, 1966). Use of seed low in P content caused a reduction in yield of root crop even though the seed was satisfactory in terms of germination percentage and field emergence. Scott and Longden (1973) found that a moderate application of P to

sugar beet seed crop gave small but consistent increases in seed size and yield but it did not affect germination. Maxon Smith (1976) working with lettuce, studied the cultivar effects, pot type, frequency of liquid feeding and feed composition on seed yield, seed weight, seed germination and progeny performance. He applied two different liquid feeds, one with P fertilizer and one without. He obtained conflicting results for seed yield and for seed weight, but there was outstanding uniformity of seed germination on progeny plant performance. Varis (1979) found an increase in mean seed weight of tomato cv. Moneymaker with increasing P level from 1.31 g/plant to 2.62 g/plant). George *et al.* (1980) reported that in tomato the combination of higher levels of N and P (0.56 g N and 0.24 g P/plant) gave better germination and seedling emergence rates of the progeny than the lower levels (0.28 g N/plant, 0.12 g P/plant).

Potassium (K) is the most abundant cation in plants, it acts as an osmotic regulator; it is essential for the synthesis of chlorophyll, proteins, carbohydrates and fats, and is an important contributor to enzyme activity, it is therefore an important and essential element in plants and seed development.

Earlier investigations of Claypool (1932) and Iwata and Eguchi (1958) with lettuce and Chinese cabbage indicated that potassium had no apparent benefit in seed development. However, Harrington (1960) found that severely potassium-deficient plants of *Capsicum frutescens* L. (pepper), gave a high proportion of abnormal seed with dark coloured embryos and seed coat. Both normal and abnormal seed from such plants had a lower percentage germination than that from control plants and its viability declined more rapidly in storage.

He also found seeds germinated within pepper fruits when the potassium deficiency was created by changing the nutrient solution abruptly from a complete one to one containing no potassium.

Scott and Longden (1973) reported consistent small increases in sugar-beet seed size and yield with moderate applications of potassium but it did not affect germination. Varis (1979) found that the mean seed weight of tomato was higher at 9.96 g K/pot than at 4.98 g K/pot). Mahmoud (1982) also working with tomato used two levels each of N, P, K to find their effect on seed yield and quality. He reported that potassium reduced the germination percentage, 100 seed weight and number of normal seedlings, where as PK and NPK interactions at high levels gave better germination after the cold test, but the controlled deterioration test produced an inconsistent result.

In a study on the effect of mother plant nutrition on French bean seed yield and quality, Gavras (1981) found N and K increased both seed yield and quality whereas P increased the seed yield and decreased seed quality. Liaw (1982) also working with French bean, reported that application of potassium which appeared as an increase in the seed content, led to a decrease in the performance of the resulting seedlings in seedling evaluation and conductivity test.

2.5.1 The effect of mineral nutrition on pea *(Pisum sativum)* yield and quality

Austin (1966b) grew peas in vermiculite and watered them with four different nutrient solutions. He examined the effect of mother plant nutrition on the growth of progeny. He found that the seeds obtained from phosphorus deficient plants contained much lower P

concentration than seeds obtained from plants not deficient in this element. Differences in the supply of mineral nitrogen had little effect on the chemical composition of seeds. The low P seeds, when grown in cultures deficient in P, produced plants which gave 20-25% lower yields in haulm and seed weight than high P seeds. But when those seeds with low P content were grown in cultures not deficient in P, there were no differences in the seed's performance. Similar results have been obtained when low- and high-P seeds were grown on a fertile field soil. Hawthorn and Pollard (1966) also working with pea, but in field conditions reported that the addition of nitrogen decreased the pea seed yield and germinability while application of phosphorus from 0-168 kg/ha produced no significant difference in bean seed yield or viability. Austin (1972) concluded that "in all areas where soil phosphorus deficiency is widespread, seed for sowing should be produced on land of high phosphorus status, to ensure that it contained the desirable high phosphorus content". Austin (1972) also reported that seed from pea plants grown in conditions of manganese deficiency had brown necrotic areas on the inside surface of the cotyledons, a symptom commonly known as ' Marsh spot'. This condition is found to affect the suitability of the peas for processing (Reynold, 1955). Leggatt (1948) found that peas harvested from a boron deficient area appeared quite normal, but when germinated in sand, they produced pale and stunted plumula lacking the normal curvature. By adding a trace of borax to the sand entirely normal plumules were obtained from deficient seeds.

Trevion and Murray (1975) studied the effects of nitrogen on pea seed production. The experiments were conducted in a glasshouse and nitrogen was applied as ammonium nitrate at seven equally spaced

intervals at nitrogen rates of 0, 50 and 100 ppm. Seven pea cultivars were used, the intermediate rate of nitrogen increased the total seed protein of five cultivars and the increase was due to an increase in protein/seed and higher seed yield. The results from this experiment demonstrate that different pea genotypes respond positively to nitrogen fertilization. Moderate increases in seed yield are accompanied by considerable increases in percentage protein content in the seed. The authors also suggested that efficiency of nitrogen translocation to seeds could be a useful indicator in the selection of genotypes for improved seed protein content.

Recent work of Browning (1980) on peas grown in the glasshouse indicated that increasing the level of nitrogen supply to the mother plant leads to an increase in the nitrogen content of the seeds. Seeds from high N treatments were generally of high vigour as evidenced by lack of hollow heart, low conductivity value of seed leachate, larger seed size, larger resulting seedling size and field emergence. Browning (1980) also found that differences in plant phosphorus supply and seed P content had less effect on seed vigour than nitrogen. Seed yield and seed vigour in a second generation glasshouse grown crop were not affected by the treatments of the first generation crop. Also in the field experiments, where there were adequate P and K in soil, Browning did not find differences in seed treatment content or seed vigour when fertilizer was applied to the plant in the field. After comparing the greenhouse and field work, she concluded that temperature at the seed maturation stage (which was higher for the glasshouse crops) may have greater effect on seed vigour than the effect of nitrogen. Browning and George (1981) reported that in one experiment higher doses of nitrogen to the pea plant in the greenhouse increased the

incidence of bleaching in the developing seeds. However, hollow heart was high in plants receiving low nitrogen and high phosphorus. Seed bleaching and hollow heart can each cause low vigour in pea seeds.

The vining pea crop is precision drilled and the achievement of target population in the field is important for crop yield and profitability (Gane, 1975). The demand of the processing industry means that pea crops are often sown in early spring when soil conditions are cold and wet. It is with these early seeded crops that emergence failure is most likely to occur. Thus the most important effect of low vigour on pea seed is failure of seedling establishment and associated loss of crop yield. As a result, there is an increasing interest and pressure in the production of high quality seeds. The present study was undertaken with a view to investigating the effect of mineral nutrition (N, P, K) of the mother plant on pea seed yield and quality and attempting to find possible explanations for the mechanism of these effects.

3. MATERIALS AND METHODS

3. Cultural Practices and Materials and Methods

3.1 General Cultural Practices For Greenhouse Experiments

In all experiments (greenhouse and field), the early maturing pea cultivar 'Sprite' was used. This is a widely grown early cutivar used by the processing industry in the U.K. Seeds were obtained from Hurst Gunson Cooper Tabel Ltd. of Witham.

Plants were grown in peat, sand medium based on that devised by Bunt (1976). Sphagnum peat and fine sand were mixed in the ratio of 3:1. To each litre of this compost the following were added:

1. 0.1 g of fritted trace element 253A (containing 2% B, 2% Cu, 12% Fe, 5% Mn, 0.13% Mo and 4% Zn).
2. 2.25 g of ground limestone, and;
3. 2.25 g of ground magnesium limestone.

The pH of the compost varied between 5.93 - 6.12, with amean of 6.

In all glasshouse experiments, the total nutrients were applied both as base and liquid. The base dressing was mixed in with the correct amount of compost at the time of mixing. The appropriate liquid feeds, according to experiment requirement, were applied weekly. These applications started when the seedlings reached the two leaf stage, two to three weeks after sowing and continued until crop maturity.

In all experiments twice the final number of plant population/pot were sown in each container, within the first 3 weeks and prior to start of liquid feeding. The subsequent seedlings were thinned to the required number. All container grown plants were staked, tied and caged during growth (see Plate 1).

Individual containers were placed in an appropriate size saucer, in order to avoid loss by leaching. Plants were irrigated

Plate 1. Plants grown in container

and looked after according to normal glasshouse practice without any artificial light. The 24 h minimum-maximum temperatures were recorded at 09.00 hours each day, during the production period of each experiment.

A fully randomized block design method was used to determine the position of each treatment within the experiments.

The following fertilizers were used to supply the different nutrients.

1. Ammonium nitrate (34% N) was used in the base dressing and liquid feed. This fertilizer provides equal amounts of ammonium and nitrate nitrogen.
2. Potassium nitrate (13% N, 46% K) was used in the liquid feed and potassium nitrate (13.8% N, 39% K) in the base dressing of the guard rows only.
3. Potassium sulphate (44% K) was used in the base dressing and liquid feeding of all the experiments.
4. Superphosphate (19% P_2O_5) was used in the base dressing and the liquid feed.

In all experiments the number of pods per plant and the air dry weight of the vines, seed and pods were recorded at harvest.

In all experiments pods were harvested by hand on a single date. Harvested pods were air dried in the laboratory for up to 6 weeks before hand threshing. Seeds were then stored in paper bags in the laboratory (temperature 20 ± 5°C and RH 20 ± 5%) before use in the seed vigour tests.

Before any vigour tests, samples of seeds from the different treatments were analysed for the following nutrient elements:

Summary of crop diaries for the four experiments.

		Glasshouse experiments			Field
		1 (1983)	2 (1984)	4 (1985)	3 (1985)
Location		Glasshouse 12	Glasshouse 10	Glasshouse, Bathampton	LARS, Bristol
Nutrients investigated		N, P, K	N, P	N, K	N, P, K
Nutrient levels		N=4, P=4, K =4	N=2, P=4	N=4, K=4	N=3, P=3, K=3
Number of treatments		64	8	16	27
Number of replicates		4	4	3	3
Number of plants/treat.		4	25	36	Average 54 pl./plot
Sowing date		3.8.83	19.6.84	21.6.85	15.5.85
Compost		GCRI	GCRI	GCRI	Field-sandy loam
Thinning out	1st	1.9.83	2.7.84	4.7.85	not thinned
	2nd	7.9.83	9.7.84	6.7.85	
	3rd	12.9.83	14.7.84	8.7.85	
Liquid feeding	1st	13.9.83	20.7.84	14.7.85	
	2nd	20.9.83	27.7.84	21.7.85	
	3rd	27.9.83	4.8.84	28.7.85	
	4th	4.10.83	11.8.84	5.8.85	
	5th	11.10.83	18.8.84	12.8.85	
Fungicides		Benelate	Dinocap	None	Dinocap
		Dinocap	-	-	-
Insecticides		Demeton-s-methyl (Metasystox 55)	Demeton-s-methyl (Metasystox 55)	None -	Demeton-s-methyl (Metasystox 55)
Herbicides		None	None	None	Opoguard
		-	-	-	-
Harvest date		20.11.83	26.9.84	3.10.85	29.9.85
Mean seed moisture content at harvest		15 - 25%	12 - 15%	10 - 14%	15 - 50%
Drying out period		6 weeks	6 weeks	5 weeks	10 weeks
Lab. storage temp.		10 - 25° C	10 - 25°C	10 - 25°C	10 -25°
	RH	50 - 80%	50 - 80%	50 - 80%	50 - 80%

nitrogen, phosphorus, potassium, magnesium, manganese, copper and iron, in addition to the standard germination test. The vigour tests used were conductivity test , seedling evaluation and the cold test as well as measuring the seed ATP content. The nutrient levels for each experiment and the materials and methods for the tests and analysis are described in this section.

3.1.1 Experiment number 1 (1983)

In this experiment, ten seeds were sown in 15 cm (6" diameter plastic pots containing 6 litres of compost, on 13th August 1983.

Nutrient treatments consisted of four levels of nitrogen (N_1, N_2, N_3 and N_4), four levels of phosphorus (P_1, P_2, P_3 and P_4) and four levels of potassium (K_1, K_2, K_3 and K_4), their interactions were tested in a randomised block design of four replicates. The total number of treatments was 64; i.e. 64 combinations of N, P and K per block making a total of 256 observations (Table 2).

Part of the nutrients in the treatments (i.e. the 1st 100 mg per plant of N, 50 mg/plant of P and 44 mg per plant of K), were applied as base dressing during the compost preparation for all the treatments. The remainder of the nutrients were applied as liquid feed throughout the growing season (Table 1). The fertilizers in the base dressing were mixed in by hand during compost preparation.

Four plants planted in 6L pots containing G.C.R.I. compost and nutrient at recommended levels were used as a guard row all the way round the crop in the glasshouse. The maximum and minimum greenhouse temperatures were recorded at 09.00 hours daily, and are presented in Figure 2. The ventilation was set at 25°C.

The number of pods per plant and the air dry weight of the vines , seeds and pods were recorded at harvest.

After pod harvest, the root systems of a randomly selected number of plants were examined for the presence of root nodules. In no case were any found indicating that the plants were not obtaining nitrogen as a result of *Rhizobium* sp. activity.

Experiment Number One (1983): Crop Diary

Location: Glasshouse number 12, University of Bath, Claverton Down.

3.8.1983 Sowing date: 10 seeds/pot in 6L pots to be thinned out to a final number of 4 plants/pot.
Variety: Sprite, sowing media: G.C.R.I. compost.

1.9.83 1st thinning out to 7 plants/pot.

7.9.83 2nd thinning out to 5 plants/pot and caging the plants up with the aid of 1 m long canes and string.

12.9.83 Final thinning out to 4 plants/pot.

13.9.83 1st liquid feed started. Total volume of liquid feed/ treatment 2 L. At each feeding session 400 ml in total to the pots in the 4 replicates i.e. 100 ml/pot or 50 ml/plant.
The 2nd, 3rd, 4th and last feedings were on 20.9, 27.9, 4.10 and 11.10. 1983.

19.9.83 Benelate was sprayed at 50 g/5 L of water to control powdery mildew.

22.9.83 Benelate spray had had very little effect.

23.9.83 Plants sprayed with Dinocap at 5 ml/5 L.

25.9.83 Dinocap spray had had a relatively good effect.

10.10.83 Dinocap spray repeated. Effective control achieved.

20.11.83 Due to high humidity and danger of seeds deteriorating in quality by possible fungus attack, a once over harvest of all treatments started and drying was allowed to continue in the laboratory for 6 weeks. Mean seed moisture content at the time of harvest (10 - 25%).

Table 1. Nutrient levels used in the first experiment.

	Total		Base	Liquid feed	Amount of fertilizer Base		Amount of fertilizer liquid feed		Exp. 1 1983
	mg/plant	equivalent kg/ha of fertilizers	mg/plant	mg/plant	mg/plant	mg/16 plants	mg/plant	mg/16 plants	
N_1	100	285	100	0	285.8	4572.8	0	0	Ammonium nitrate NH_4NO_3 (35% N)
N_2	150	428.6	100	50	285.8	4572.8	142.9	2286.4	
N_3	300	857.1	100	200	285.8	4572.8	571.4	9145.6	
N_4	500	1428.5	100	400	285.8	4572.8	1142.8	18291.2	
P_1	50	263	50	0	263.2	4210.5	0	0	Superphosphate (19% P_2O_5)
P_2	69	363	50	19	263.2	4210.5	100	1600	
P_3	126	663	50	76	263.2	4210.5	400	6400	
P_4	202	1063.2	50	152	263.2	4210.5	800	12800	

Table 1 continued

	Total		Base	Liquid feed	Amount of fertilizer Base		Amount of fertilizer liquid feed		Exp. 1 1983
	mg/plant	equivalent kg/ha of fertilizers	mg/plant	mg/plant	mg/plant	mg/16 plants	mg/plant	mg/16 plants	
K_1	44	100	44	0	100	1600	0	0	Potassium sulphate K_2SO_4 (44% K)
K_2	64	145.5	44	20	100	1600	45.5	728	
K_3	124	281.8	44	80	100	1600	181.8	2908.8	
K_4	204	463.6	44	160	100	1600	36.36	5817.6	

Table 2. Experiment Number 1. Nutrient combination (1984).

Treatment No.	Nutrient combination	Treatment No.	Nutrient combination
1	N_1 K_1 P_1	33	N_1 P_3 K_3
2	N_2 K_1 P_1	34	N_1 P_4 K_3
3	N_3 K_1 P_1	35	N_1 P_2 K_4
4	N_4 K_1 P_1	36	N_1 P_3 K_4
5	N_1 K_1 P_2	37	N_1 P_4 K_4
6	N_1 K_1 P_3	38	N_2 P_2 K_2
7	N_1 K_1 P_4	39	N_2 P_3 K_2
8	N_1 K_2 P_1	40	N_2 P_4 K_2
9	N_1 K_3 P_1	41	N_2 P_2 K_3
10	N_1 K_4 P_1	42	N_2 P_3 K_3
11	N_2 K_1 P_2	43	N_2 P_4 K_3
12	N_2 K_1 P_3	44	N_2 P_2 K_4
13	N_2 K_1 P_4	45	N_2 P_3 K_4
14	N_2 K_2 P_1	46	N_2 P_4 K_4
15	N_2 K_3 P_1	47	N_3 P_2 K_2
16	N_2 K_4 P_1	48	N_3 P_3 K_2
17	N_3 P_2 K_1	49	N_3 P_4 K_2
18	N_3 P_3 K_1	50	N_3 P_2 K_3
19	N_3 P_4 K_1	51	N_3 P_3 K_3
20	N_3 P_1 K_2	52	N_3 P_4 K_3
21	N_3 P_1 K_3	53	N_3 P_2 K_4
22	N_3 P_1 K_4	54	N_3 P_3 K_4
23	N_4 P_2 K_1	55	N_3 P_4 K_4
24	N_4 P_3 K_1	56	N_4 P_2 K_2
25	N_4 P_4 K_1	57	N_4 P_3 K_2
26	N_4 P_1 K_2	58	N_4 P_4 K_2
27	N_4 P_1 K_3	59	N_4 P_2 K_3
28	N_4 P_1 K_4	60	N_4 P_3 K_3
29	N_1 P_2 K_2	61	N_4 P_4 K_3
30	N_1 P_3 K_2	62	N_4 P_2 K_4
31	N_1 P_4 K_2	63	N_4 P_3 K_4
32	N_1 P_2 K_3	64	N_4 P_4 K_4

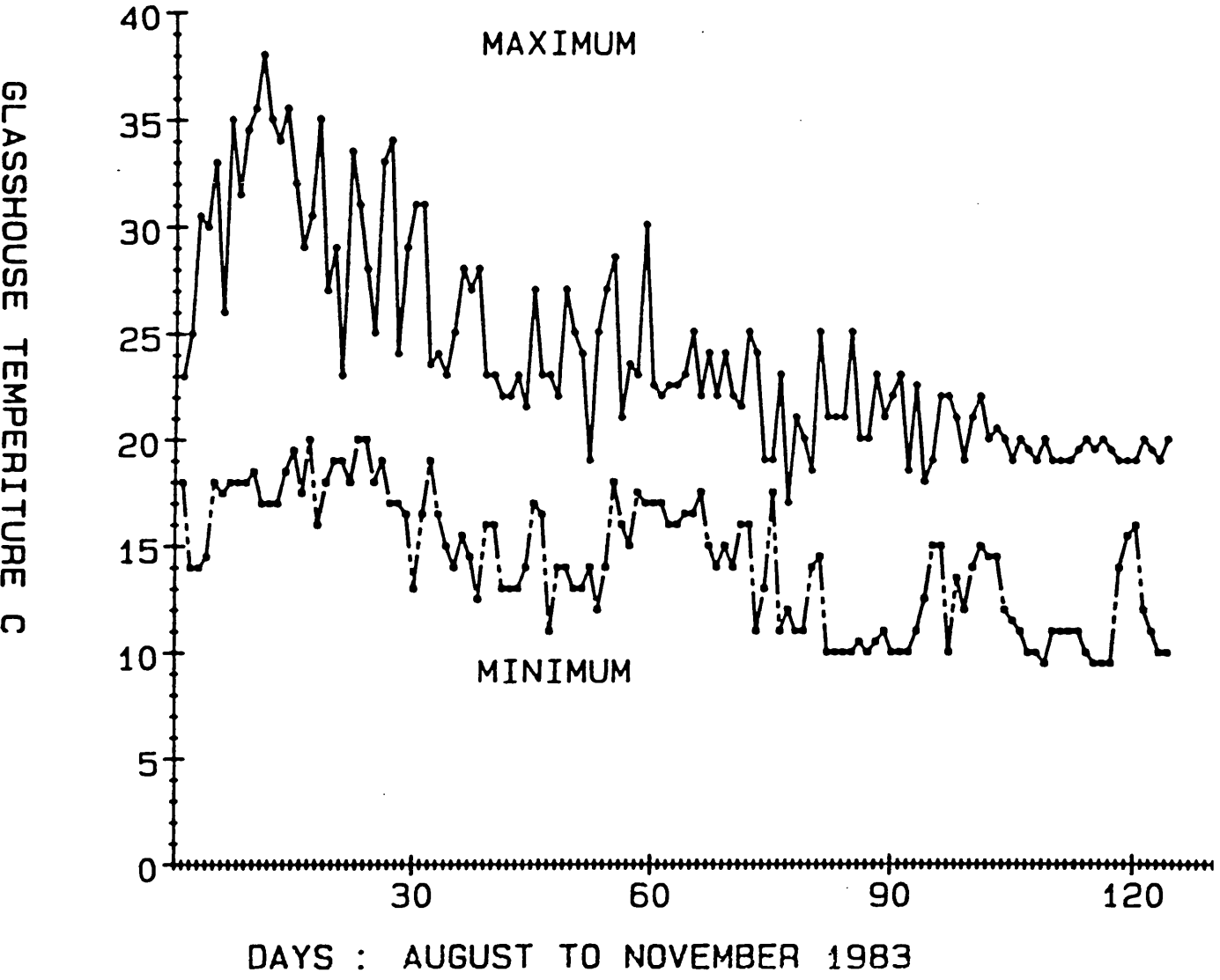

Figure 1. The maximum and minimum glasshouse air temperatures recorded daily at 09.00 hours during experiment 1.

3.1.2 Experiment Number 2 (1984)

Records from the 1983 nutrition experiment showed that increasing N and P levels increased seed yield and improved quality. It was therefore decided to investigate the effect of N and P and their interaction at constant K level on a smaller number of nutrient treatments, but larger scale of production per treatment in order to increase the seed number and yield per treatment for improved flexibility in further quality assessments.

In this experiment two levels of nitrogen (N_1 and N_2) and four levels of phosphorus (P_1, P_2, P_3 and P_4) were used (Table 4). Their interaction was tested in a randomised block deisgn of four replicates. The number of treatments were eight (Table 3) per block making a total of 32 observations. However, each treatment per block consisted of five 8 L pots containing 5 plants, making 5 x 5 = 25 plants per treatment in each replicate and 25 x 4 = 100 plants per treatment in the four replicates requiring 5 x 8 x 4 = 160 L of compost per treatment. Eight lots of 160 L compost were prepared using the G.C.R.I. system of mixing peat and sand in the ratio of 3:1 as described before.

In this experiment, twelve seeds were sown in 20 cm (8") diameter pots containing 8 L of compost on 19th June 1984. As with the first experiment, the total nutrient treatments were applied in parts as follows:

Nitrogen, ⅓ base, ⅓ pre-flowering and ⅓ liquid feed.

Phosphorus ⅔ base and ⅓ liquid feed. and

Potassium all as base dressing.

4 plants grown in 6 L pots containing the G.C.R.I. compost and the equivalent of recommended fertilizers were grown and used as a guard row all the way round the crop in the glasshouse. The maximum and minimum greenhouse air temperatures were recorded daily at 09.00 hours and are presented in Figure 3. The ventilation was set at 25°C. The plants were watered as required.

The pH of the compost before the addition of nutrient was between 5.94 and 6.13 with a mean of 6.00. The pH of the compost was also measured for all the treatments on 30th June 1984 and 25th August 1984 and are presented in Figure 4.

Table 3. The treatment number and corresponding treatment combination used in Experiment 2.

Treatment No	Treatment Combination		Treatment No	Treatment combination	
1	N_1	P_1	5	N_2	P_1
2	N_1	P_2	6	N_2	P_2
3	N_1	P_3	7	N_2	P_3
4	N_1	P_4	8	N_2	P_4

For details of the crop husbandry, see the crop diary on page 65 .

Table 4. Nutrient levels used in Experiment 2, 1984.

	Total		Base ⅓N, ⅔P, ⅓K g per 100 plant	Pre-flowering ⅓ N g per 100 plant	liquid feed ⅓N + ⅓P g per 100 plants	Total fertilizer g per 100 plants	
	mg/plant	equivalent kg/ha of fertilizer					
N_1	100	285.7	3.33	3.33	3.33	28.9	Ammonium
N_2	1000	2857.2	33.3	33.3	33.3	285.42	nitrate 35% N
P_1	25	131.6	1.67	-	0.83	13.20	super
P_2	250	1315.8	16.7	-	8.3	131.85	phosphate
P_3	500	2631.6	33.3	-	16.7	262.95	19% P_2O_5
P_4	1000	5263.1	66.7	-	33.3	526.50	
K	100	2273	10	-	-	22.73	potassium sulphate 44% K.

Experiment 2 (1984) Crop Diary

Location: Glasshouse number 10, University of Bath, Claverton Down.

19.6.84 Sowing date: variety Sprite. 12 seeds in 8 L pots to be thinned out to a final number of 4 plants/pot. Sowing media G.C.R.I. compost.

2.7.84 1st thinning out down to 8 plants/pot.

9.7.84 2nd thinning out down to 6 plants/pot and caging the plants up with the aid of 1 m canes and strings.

14.7.84 Final thinning out down to the required 5 plants/treatment.

16.7.84 Flower buds observed and developing and the first flower has opened in the experiment, therefore ⅓ of nitrogen nutrition destined for this time of application was applied.

20.7.84 Liquid feeding commenced.

⅓ N + ⅓ P were dissolved in 2 L water. They were applied over a period of 5 weeks at weekly intervals, i.e. 400 ml/week/20 pots/treatment. Therefore, each pot in each treatment received 20 ml of the stock solution diluted to 200 ml. 2nd, 3rd, 4th and final feedings were on 27.7, 4.8, 11.8 and 18.8.1984.

During the production period the crop was sprayed with appropriate chemicals for control against mildew and mites (see Section 3.1, page 54).

26.9.84 The crop was finally harvested. A once over harvest of all treatments started and drying was allowed to continue in the laboratory for 6 weeks. Mean seed moisture content at the time of harvest was 12 - 15%. Seeds were stored in

paper bags inside plastic bags in the laboratory, for one to six months before use in seed vigour tests. The air temperature and humidity during the storage period ranged from 10 - 25°C and 50 - 80% RH respectively.

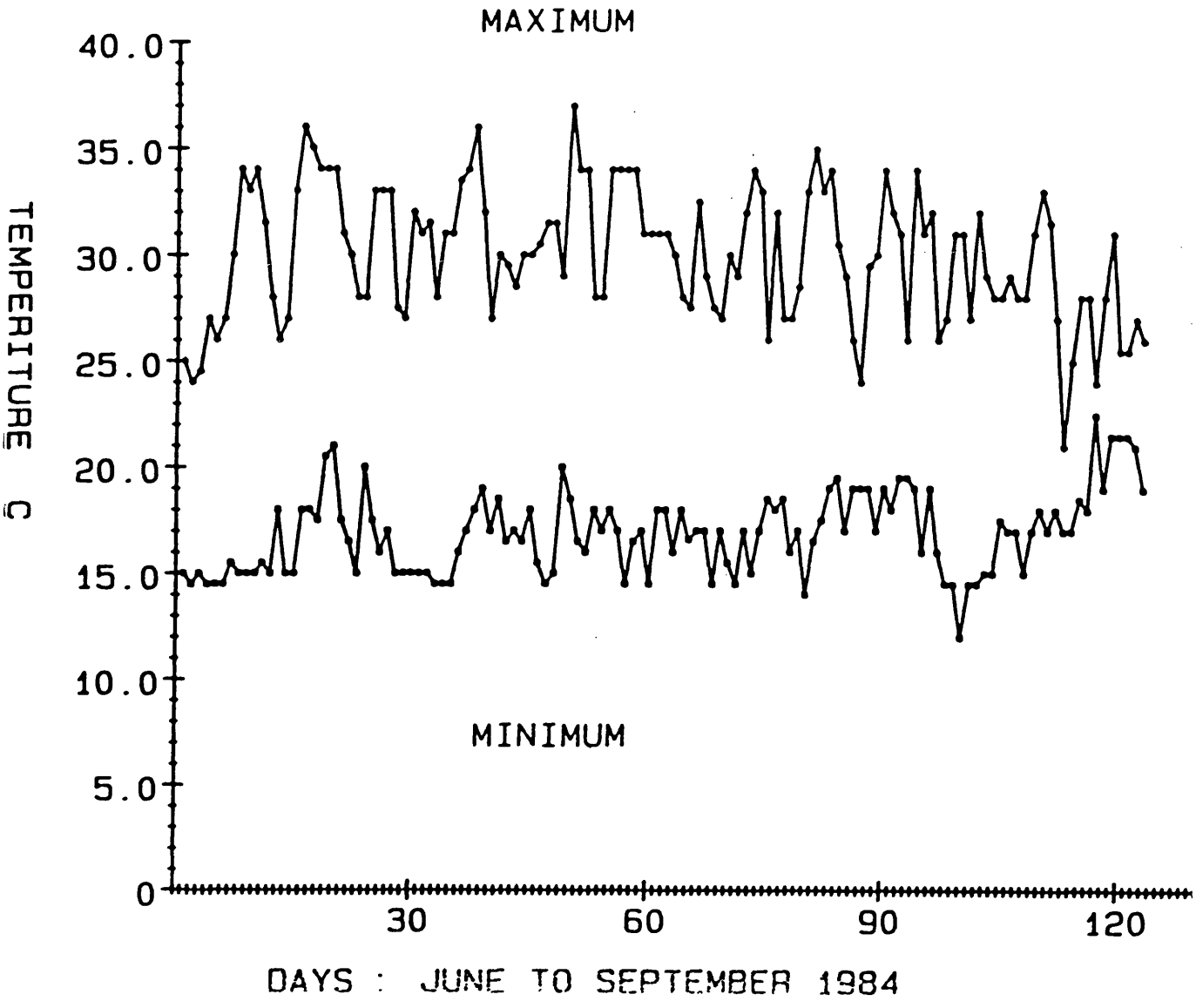

Figure 3. The maximum and minimum glasshouse air temperatures recorded daily during the experiment 2.

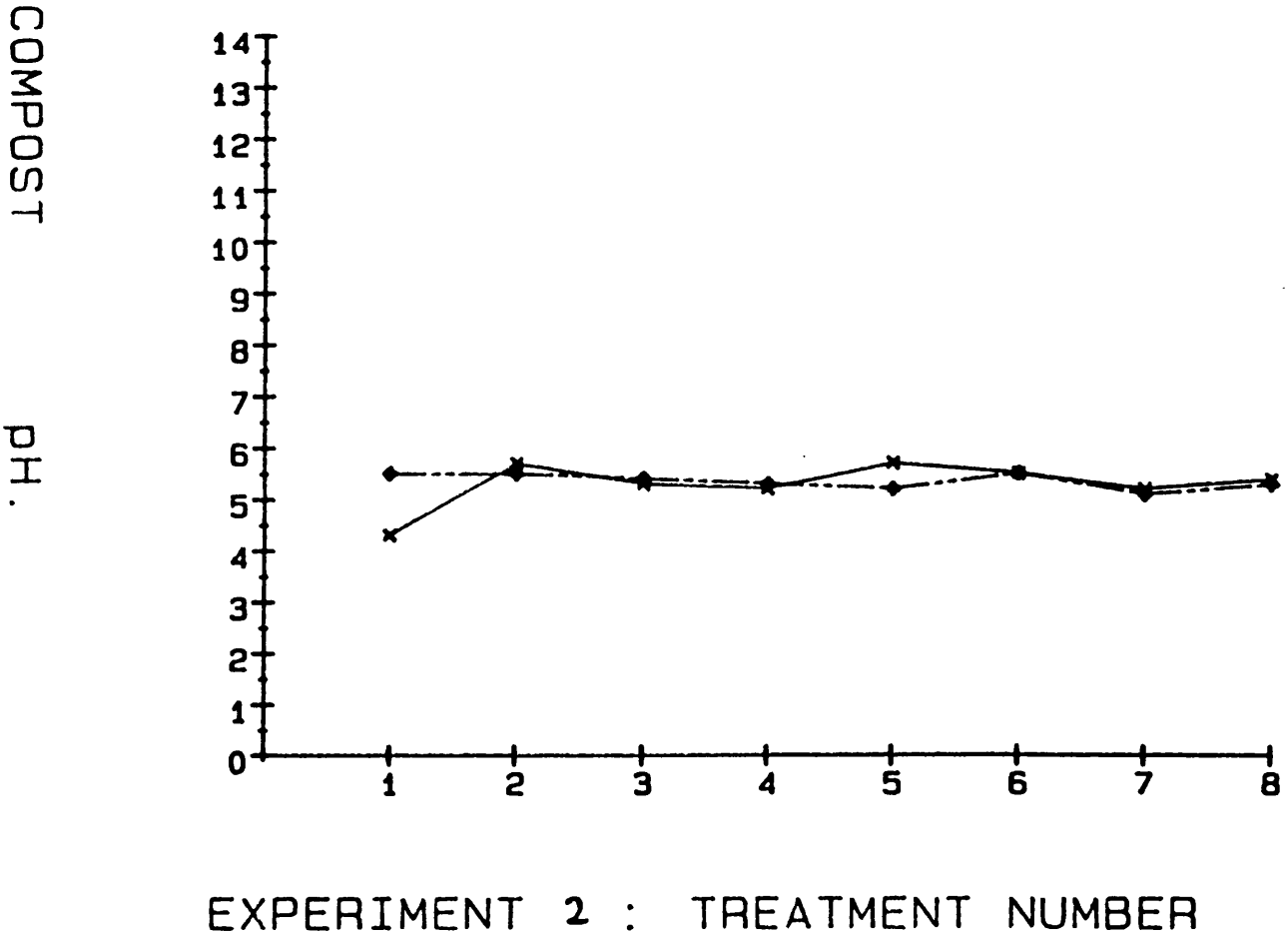

Figure 4. The compost pH measured on two separate occasions in experiment 2.

X = measurement on 30.6.1984

◆ = measurement on 25.8.1984

3.1.3 Experiment 3 (1985) Outdoor seed production

Following the overall conclusion from the two previous experiments (1 and 2), it was decided to carry out an outdoor experiment on a site with relatively low nutrient levels in particular phosphorus. Following consultations with ADAS, Bristol, and the University field staff, Long Ashton Research Station at Bristol offered a site which was known to be low in phosphorus.

Three soil samples were taken from the site and delivered to ADAS's soil department for N, P, K analysis, and its assessment for the suitability of the site for the objectives of the experiment. The P and K indices were reported to be 1 and 2 respectively (Table 5), thus further operations were started. Also ADAS computers recommended an application rate of fertilizers for growing a crop of peas and their recommendation formed the basis of the nutrition levels in this experiment. There is no separate recommendation for a pea seed crop.

Nutrient treatments consisted of three levels of nitrogen (N_1, N_2 and N_3), three levels of phosphorus (P_1, P_2 and P_3) and three levels of potassium (K_1, K_2 and K_3). Their interactions were tested in a randomised block design of 3 replicates. The total number of treatments was 27, i.e. 27 combinations of N, P(and K per block, making a total of 81 observations (Table 7).

Site preparation

History: The site had been ploughed in autumn by Long Ashton Research Station staff and was left over winter. It had been down to grass the previous year and plum seedling orchard the previous twelve years. Of a reasonably textured silt loam, on a south facting

slope, it was considered to be a good site, except that the nearest irrigation supply tap was just over a mile at the bottom of the slope, so arrangements were made to have a water tank always available on site.

Preparation: On the selected site a 540 m^2 piece (27 m x 20 m) was fenced off, and prior to marking out a Kubota tractor/rotavator was used to turn the soil. Ground limestone was added at a rate of 0.9 kg/m^2 to adjust the pH. The lime was rotavated in and the ground was then left for one week before planting.

Each replicate consisted of 27 plots each 4 m^2 (2 x 2) in size. Allowing for the size of the experimental area, it was possible to have 3 rows of plots, each row consisting of 9 plots and separated by 1 m wide guard rows, as shown in Figure 5.

Fertilizers for each plot (Table 8) were mixed separately and were applied on 10.5.85 to the plots by hand and were mixed into the top 10 cm the soil by a pedestrian rotavator.

On 15.5.85, 200 seeds were sown in each plot in 5 rows of 40 cm apart and 5 cm apart within rows. This gives a plant population of 50 per m^2 below the recommended 75 per m^2 by NIAB (Anon, 1980b).It was thought a lower population would reduce competition between plants. Plots were then covered with netting as protection against birds.

With the cool soil temperature of 13 - 16°C in mid May, it took 10 to 15 days for seedlings to emerge. Unfortunately the seeds were only dressed with fungicides and problems began with earwig and other insects' damage to seedlings and by28.6.85 some plots,

especially the ones in replicate III had lost up to 50% of their seedlings.

In order to rectify the situation, the plots were reseeded and the plant populations were brought back up to 50 / m^2 but this meant that there were now two populations of plants, one being almost 15 - 18 days younger than the rest, and the experiment was continued.

On 16.5.85, the pre-emergence herbicide Opogard (a.i. Terbutryne with terbuthylazine) was applied at a rate of 170 g per 500 m^2 and thereafter, the application of herbicides was down to a minimum, and weed control was mainly by hand in order to reduce the quantity of chemicals applied onto the plants which might have some interaction with plants' biochemistry and indirectly affect the nutrient/seed interaction.

During the months of June and July the plant growth was steady and reasonable, despite the lower than average temperatures as claimed by the meterological section of the LARS. Irrigation water was applied 12 times in total during the early parts of the month of June and early July and then came the wettest August in the history of LARS, which led to even further plant losses due to fungus attack (see the attached temperature and rainfall; Figures 6 and 7).

It was finally decided to harvest the crop on 29.9.85, as the continuation of the rain and high humidity was not giving the plants and the mature pods a chance to dry in the field, and if it had stayed on,the seeds would either have rotted or germinated on the plants. At the time of harvest the seed moisture content was as high as 50%. The whole plants were harvested at ground level, and only from the 3 centre rows from each plot and were brought back to

Bath and hung in the Bathampton field station glasshouse to dry gradually.

Almost four weeks later,pods were separated from the plants and the following observations recorded: number of plants per plot and weight of dry plants.

The pods containing seeds were left for another 4 weeks to dry out further before threshing.

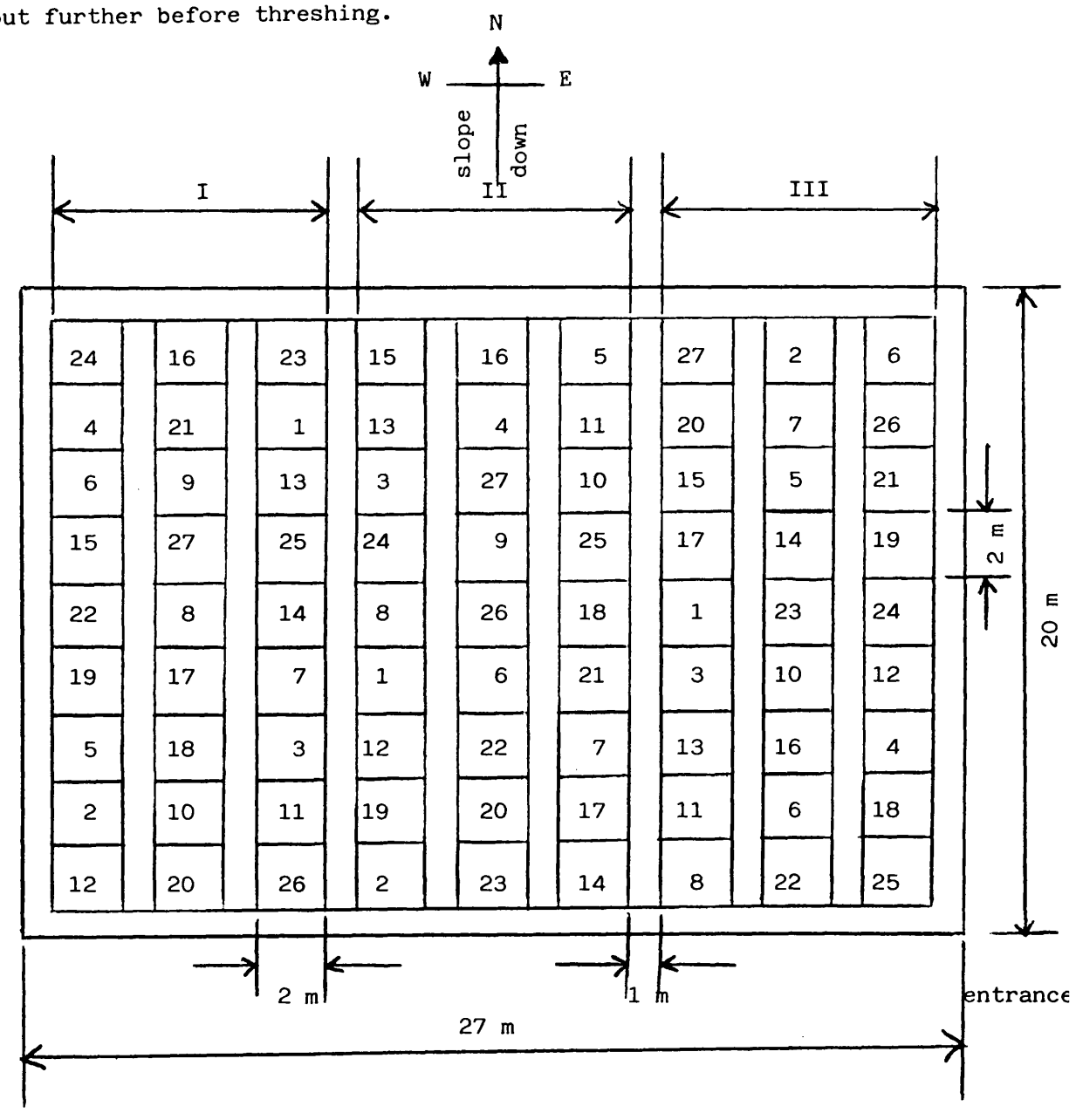

Figure 5. The experimental layout used in Experiment 3.

Table 5. ADAS Soil analysis and fertilizer recommendation

SOIL DATA		
Soil texture	Silt loam	
pH	5.9	
Phosphorus	11 mg/L	INDEX 1
Potassium	186 mg/L	INDEX 2
Magnesium	139 mg/L	INDEX 3
Nitrogen		INDEX 1

Lime and Fertilizer recommendation for green peas		g/m^2
Ground limestone/chalk	9 t/ha	900
Nitrogen	nil (25 kg/ha for early crop)	2.5
Phosphate	50 kg/ha	50
Potash	25 kg/ha	2.5

Table 6. Nutrient levels in Experiment 3, g/m^2

Nutrient \ Level	1	2	3
N	0	2.5	7.5
P	0	5.0	15.0
K	0	2.5	7.5

Note on levels:

1 = no fertilizer addition

2 = brought up to the recommended levels

3 = brought up to 3 times the recommended levels

Table 7. The nutrient combination used in Experiment 3

TREATMENT										
No	Combination			No	Combination			No	Combination		
1	N_1	P_1	K_1	10	N_2	P_1	K_1	19	N_3	P_1	K_1
2	N_1	P_1	K_2	11	N_2	P_1	K_2	20	N_3	P_1	K_2
3	N_1	P_1	K_3	12	N_2	P_1	K_3	21	N_3	P_1	K_3
4	N_1	P_2	K_1	13	N_2	P_2	K_1	22	N_3	P_2	K_1
5	N_1	P_2	K_2	14	N_2	P_2	K_2	23	N_3	P_2	K_2
6	N_1	P_2	K_3	15	N_2	P_2	K_3	24	N_3	P_2	K_3
7	N_1	P_3	K_1	16	N_2	P_3	K_1	25	N_3	P_3	K_1
8	N_1	P_3	K_2	17	N_2	P_3	K_2	26	N_3	P_3	K_2
9	N_1	P_3	K_3	18	N_2	P_3	K_3	27	N_3	P_3	K_3

Table 8. The nutrient levels used in Experiment 3

	kg/ha	g/m^2	g per m^2 of fertilizers	
N_1	0	0	0	ammonium nitrate 35% N
N_2	25	2.5	7.6	
N_3	75	7.5	30.4	
P_1	0	0	0	superphosphate 19% P_2O_5
P_2	50	50	27.8	
P_3	150	150	83.3	
K_1	0	0	0	potassium sulphate 44% K
K_2	25	25	5.6	
K_3	75	75	16.7	

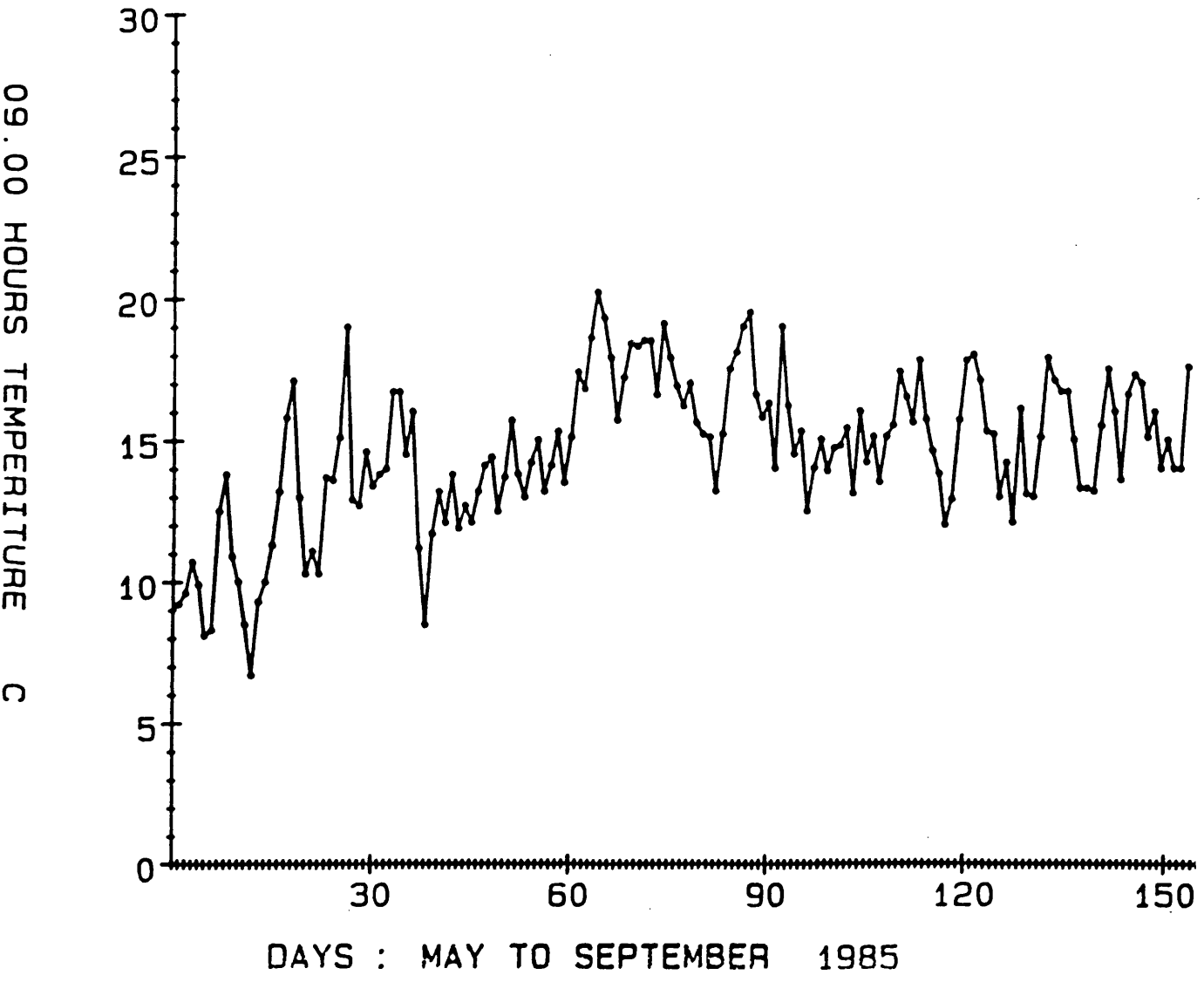

Figure 6. The daily air temperatures recorded at 09.00 hours by the Long Ashton Research Station metereological office.

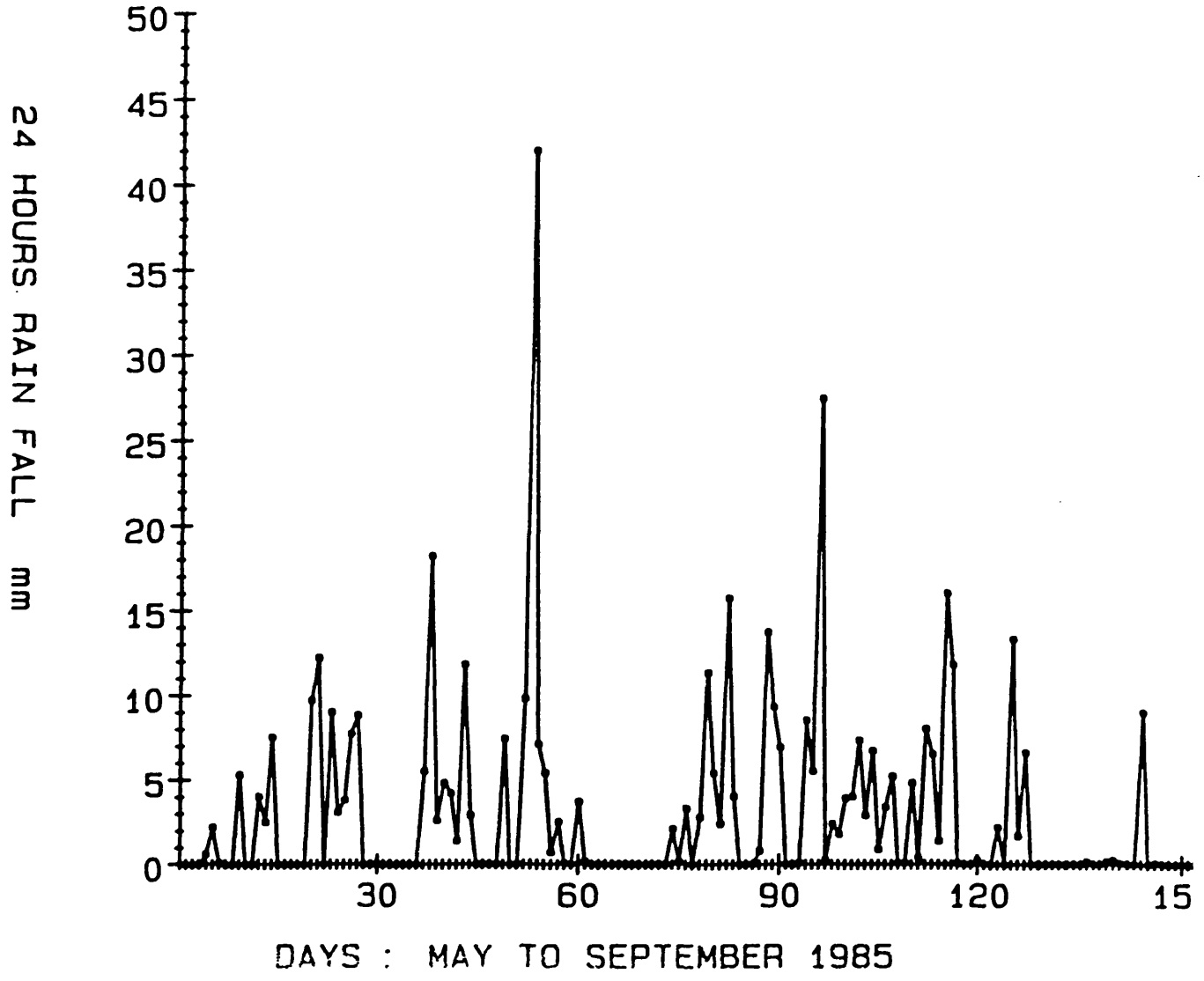

Figure 7. The 24 hours rainfall recorded daily at 09.00 hours by the Long Ashton Research Station metereological office.

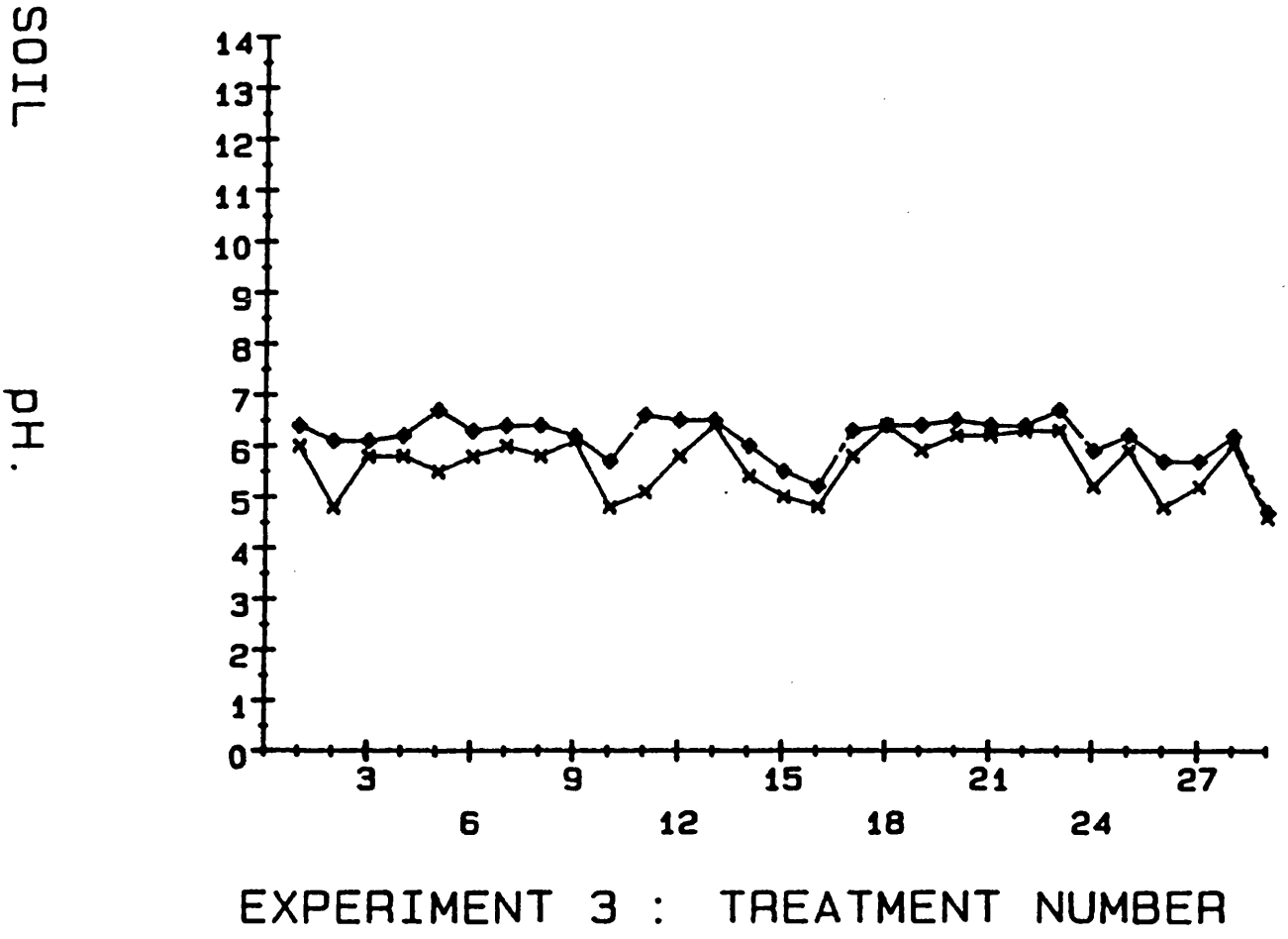

Figure 8. Soil pH measured on two separate occasions in the treatments of the second replicates. Treatment 28 is Guard row and 29 is the untreated land in Experiment 3.

X = 10th June 1985

♦ = 2nd September 1985

3.1.4 Experiment number 4 (1985)

Although the results from the 1983 and 1984 experiments showed a greater influence on seed yield and quality by N and P nutrition, the K nutrition could not be ruled out as ineffective. For this experiment it was then decided to look at the effect of N and K and their interactions at constant P level on a smaller number of treatments than Experiment One.

For this experiment, four levels of N (N_1, N_2, N_3 and N_4) and four levels of K (K_1, K_2, K_3 and K_4) (see Table 9) were used and their interactions were tested in a randomised block design of 3 replicates. Sixteen treatments per block were used (Table 10) making a total of 48 observations. However each treatment per block consisted of two 36 L compost bags supporting a final plant population of 18. For each treatment in all blocks 216 L of compost mix as described before, were prepared, using the G.C.R.I. system.

In this experiment, 40 seeds were sown in 50 cm diameter plastic non rigid 40 L growing containers, contaiing 36 L of compost on 21.6.86. As with the other two glasshouse experiments, the total nutrients applied were in two parts as follows:

Nitrogen ⅔ base and ⅓ liquid feed

Potassium ⅔ base and ⅓ liquid feed

and all phosphorus was applied as a base dressing.

4 plants grown in 6 L pots containing the compost mix and nutrient at recommended levels were used in the guard row all the way round the crop in the glasshouse.

The maximum and minimum greenhouse temperatures were recorded daily and are presented in Figure 9. The ventilation was

set at 25°C. Plants were watered as required. For details of the crop husbandy, see the crop diary, on page 80.The pH of the compost was measured on two separate occasions, the first time on 15.7.85 and the second time on 13.9.85 and are presented in Figure 10.

Experiment 4. 1985: Crop Diary

Location: Bathampton Field Station. Glasshouse No. 1.

21.6.85 Sowing date, variety Sprite. 40 seeds in 36 L non-rigid growth bags to be thinned out to a final number of 18 plants/bag. Sowing media was G.C.R.I. Compost mixture.

4.7.85 1st thinning out to 30 plants per bag.

6.7.85 2nd thinning out to 20 plants per bag, caging the plants up with the aid of 1 m canes and strings.

8.7.85 Final thinning out to the final required 18 plants/bag

14.7.85 Liquid feeding started.

⅓ N and ⅓ K were dissolved in 1500 ml of water. They were applied over a period of 5 weeks at weekly intervals i.e. 300 ml/week/6 pots in each treatment. This means each growing bag received 50 ml of the stock solution, diluted to 200 ml.

2nd, 3rd, 4th and final feedings were on 21.7, 28.7, 5.8 and 12.8.1985.

3.10.85 The crop was harvested. A once over harvest of all treatments started and further drying of pods allowed to continue in the laboratory for 6 weeks. Mean seed moisture content at the time of harvest was 8 - 10%. Seeds after depodding were stored in paper bags inside plastic bags in the laboratory for one to six months before use in seed vigour tests. The air temperature and humidity during the storage period ranged from 10 - 25°C and 50 - 80% RH respectively.

Table 9. Nutrient levels and fertilizer quantities used in Experiment 4

	Total mg/plant	Total equivalent kg/ha	Total Fertilizers g for 108 plants in 216 L of compost		Base ⅔ N ⅔ K ⅓ P	Liquid feed ⅓ N ⅓ K
N_1	0	0	0		0	0
N_2	100	285.7	30.9	NH_4NO_3	20.6	16.3
N_3	500	1428.6	154.3	35% N	102.8	51.4
N_4	1000	2857.1	300.9		200.6	100.6
K_1	0	0	0		0	0
K_2	50	111.1	12.0	K_2SO_4 45% K	8.0	4.0
K_3	250	555.6	60.0		40.0	20.0
K_4	500	1111.1	120.0		80.0	40.0
P	250	1315.8		145.83 super-phosphate 18% P_2O_5	145.83	

Table 10. The treatment number and nutrient combination used in Experiment 4

TREATMENT											
No	Combination		No	Combination		No	Combination		No	Combination	
1	N_1	K_1	5	N_2	K_1	9	N_3	K_1	13	N_4	K_1
2	N_1	K_2	6	N_2	K_2	10	N_3	K_2	14	N_4	K_2
3	N_1	K_3	7	N_2	K_3	11	N_3	K_3	15	N_4	K_3
4	N_1	K_4	8	N_2	K_4	12	N_3	K_4	16	N_4	K_4

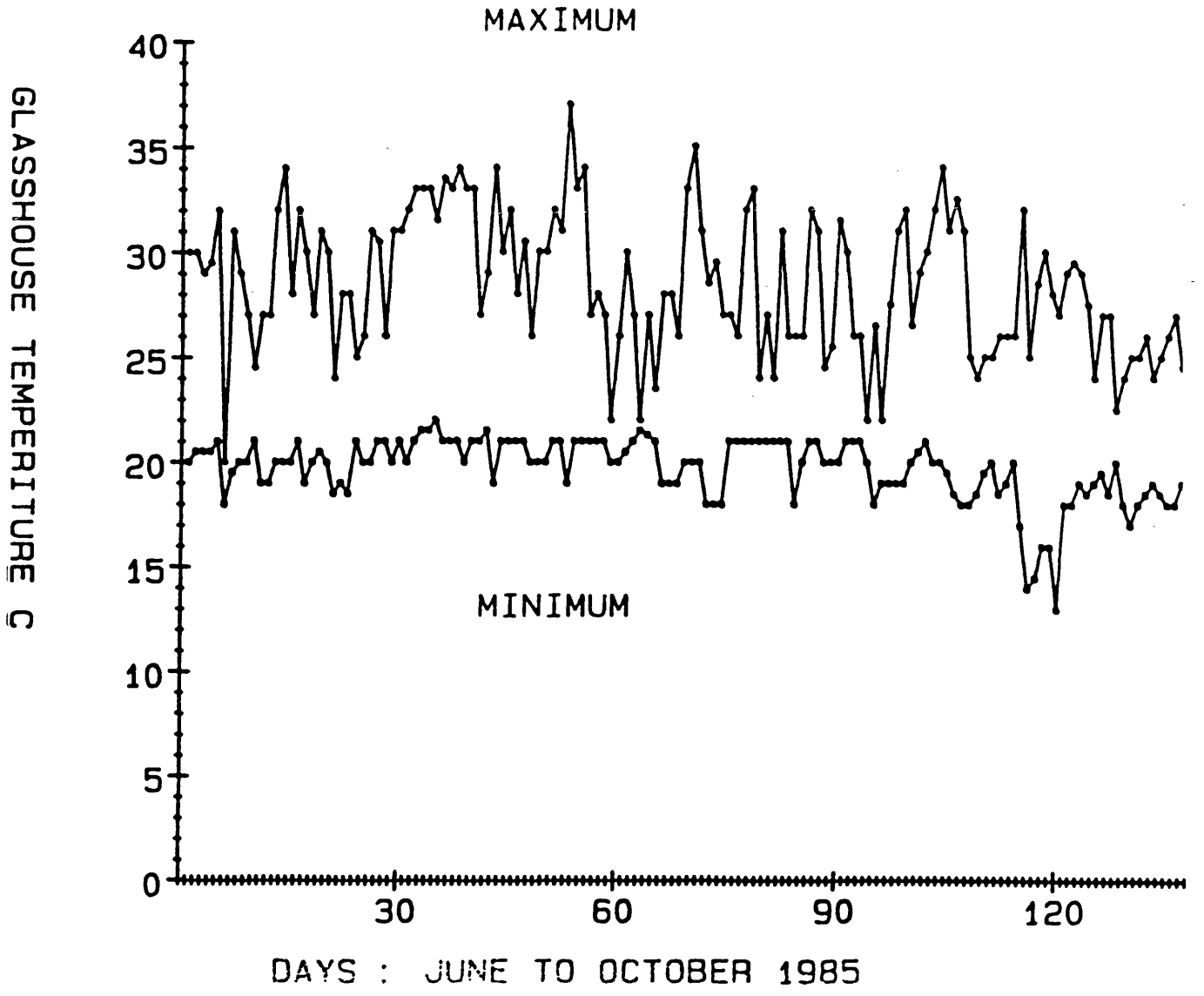

Figure 9. The greenhouse maximum and minumum air temperatures measured daily during Experiment 4.

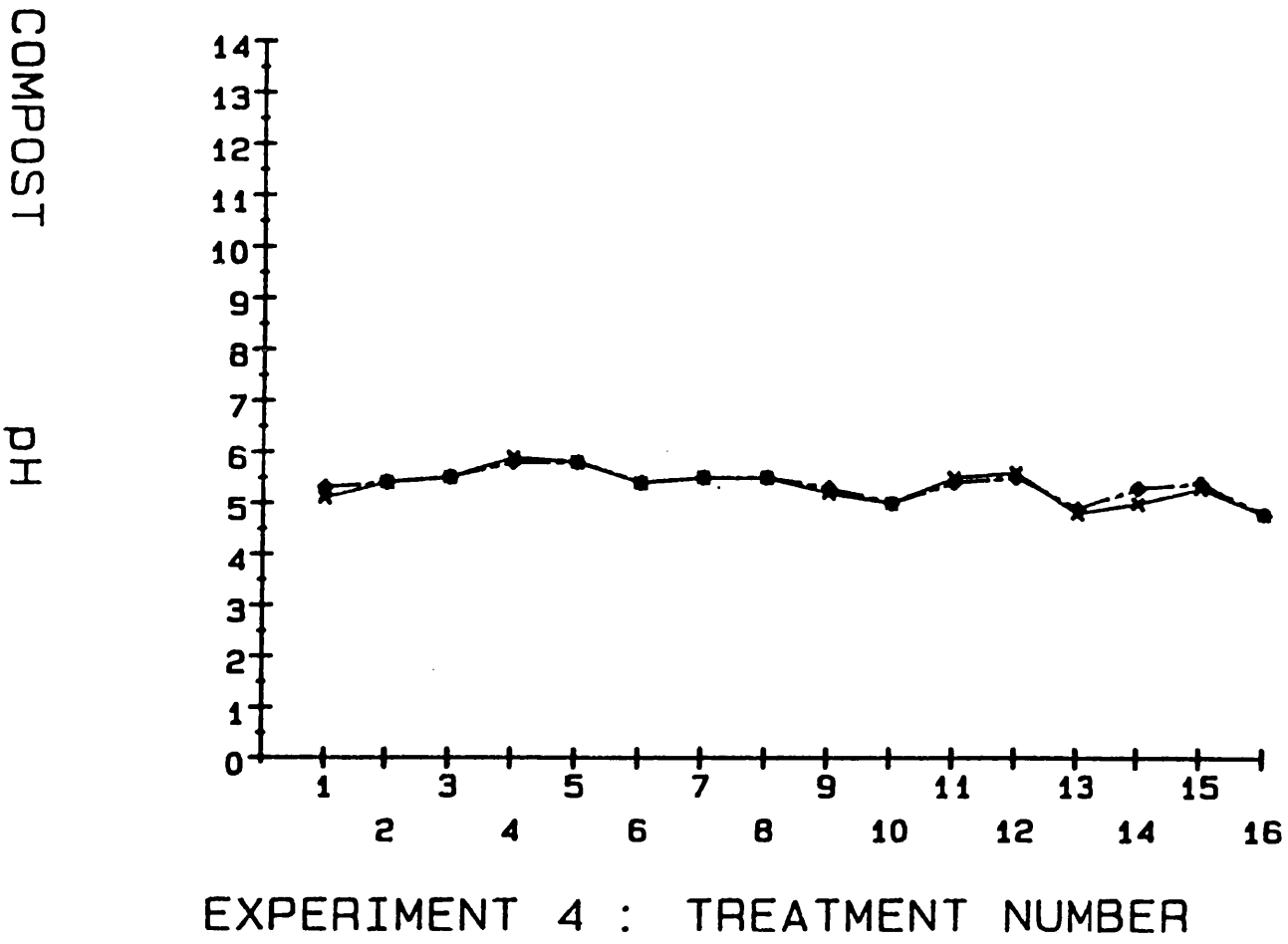

Figure 10. The compost pH measured on two separate occasions during Experiment 4.

X = 15th July 1985

◆ = 13th September 1985

At the time and after harvest the following data were collected or calculated from the treatments in each replicate for all experiments, unless where otherwise stated.

i) Plant growth as in plant dry weight per plant - without pods and seeds;

ii) Seed yield

a) Number of pods per plant (except experiment 3)

b) Weight of empty pods per plant (except experiment 3)

c) Number of seeds per plant

d) Weight of air dried seeds per plant

e) Number of seeds per pod (except experiment 3)

iii) Analytical data:

a) Seeds'total N, P, K and Mg conent per g of oven dried seeds (macro-nutrients)

b) Seeds'total Mn, Fe and Cu content per g of oven dried seeds (micro-nutrients)

iv) Seed quality:

a) Mean seed weight - a reflection of seed size

b) 1000 seed weight (only in experiment 3)

c) Standard germination test - Total seedling dry weight. % germination, % normal seedlings.

v) Seed vigour test:

a) Seed conductivity test per g of air dried seeds

b) Cold test - total seeding dry weight, % germination.

c) ATP content in seeds after 24 hours imbibition in pm per g of air dried seeds in experiment 2 only.

The following is the materials and methods for the above analytical, quality and vigour measurements.

3.2 Materials and Methods for the Seed Nutrient Content Analysis

3.2.1 Determination of total nitrogen

The determination of total nitrogen in soil, plant and other compolex heterogenous materials containing several forms of nitrogen, presents many difficulties (Bremner, 1963).

Two methods have gained acceptance for determination of total N, the Kjeldahl method, which is essentially a wet oxidation procedure, and the Dumas method, which is fundamentally a dry oxidation (i.e. combustion) technique (Bremner, 1963).

In the Kjeldahl method, the N in the sample is converted to ammonium (NH_4) by digestion with concentrated H_2SO_4 containing a catalyst (see below), and the ammonium is determined titrimetrically. In the classic Dumas method, the sample is heated with copper oxide at a high temperature (usually 500°C) in a stream of purified CO_2 and the gases liberated are led over hot copper to reduce nitrogen oxide to N_2 and the volume of N_2 gas is measured.

The Dumas method is time-consuming and complicated, and the comparatively rapid and simple Kjeldahl method is usually preferred, and was used to measure nitrogen content in leaf and seed in these experiments.

3.2.1.1 Total nitrogen analysis by the Kjeldahl method

Principle: The Kjeldahl procedure generally employed for determination of total N involves two steps:

i) Digestion of the sample to convert N to ammonium;

ii) Determination of the ammonium in the digest.

i) Digestion

Nitrogen in the sample is converted to ammonium nitrogen by digestion with concentrated sulphur acid. The catalysts most frequently employed for digestion are those containing Se, Hg or Cu. Their efficiency in producing rapid clearing decreases in the order Se > Hg > Cu, but both Se and Hg are very toxic and should be handled with care. Also when a digestion treated with Hg is mixed with alkali, some of the ammonium in the digest reacts with the mercuric oxide and is precipitated by the alkali to form a mercury ammonium complex, which is not readily liberated by distillation, thus there is a likelihood of inaccuracies.

ii) Determination of ammonium nitrogen

The ammonium liberated during digestion is distilled into H_3BO_3 and titrated with standard H_2SO_4:

$$NH_3 + H_3BO_3 \longrightarrow NH_4^+ + H_2BO_3^-$$

$$H^+ + H_2BO_3^- \longrightarrow H_3BO_3$$

Several indicators including methyl orange and congo red can be used, but general experience by many research workers, has been that the sharpest points are obtained using mixed indicators such as tetrabromophenol blue-methyl red (Stoverand and Sandin, 1931), methylene blue-methyl red (Meeker and Wagner, 1933), or bromocresol green-methyl red (Ma and Zuazaga, 1942), quoted in Hadavizadeh (1982).

3.2.1.2 Total nitrogen analysis using the Tecator Kjeltec System

The Tecator Kjeltec system consists of digestion, distillation and titration units.

Digestion

Materials:

1. Sulphur acid approx. 98% w/w
2. Kjeltabs CK $CuSO_4 8H_2O$ catalyst tablets
3. Deionised water.

Method:

Sample solutions for total N analysis were prepared as follows for all the four experiments:

½ g of sample (leaf or seed), oven dried (102°C for 1 h), ground to pass 1 mm mesh, was transferred into a digestion tube. Two Kjeltabs CK $CuSO_4 8H_2O$ catalyst tablets were added, followed by 15 ml of H_2SO_4 98% w/w. The tube was then very carefully and gently placed in the digestion unit which had been preheated to 420°C and the mixture was allowed to remain in the unit for ½ hour or until it went clear whichever was the earliest. At the end of this period, the tube was taken out and allowed to cool. When cooled 75 ml of deionized water was added very carefully and reheated until all the soluble solids were dissolved. The solution was retained for N analysis.

3.2.1.3 Distillation and Titration

Materials

1. Ammonium nitrogen standard solution containing 0.28 mg N/ml. Dry ammonium sulphate at 102°C for 1 hour and cool in a desiccator. 0.321 g of the dried salt was dissolved in 500 ml of deionized water and made up to 1 L.
2. Boric acid solution: approximately 4% w/v
3. Sodium hydroxide solution: 50% m/v.
4. Sulphuric acid 0.05 M.

Method

The distillation unit was steamed out for 20 minutes. 10 ml of the ammonium nitrogen standard solution was transferred into a digestion tube and was connected to the distillation unit. A conical flask containing 25 ml of boric acid indicator was placed under the return tube to collect the distillate. 25 ml of sodium hydroxide 50% m/v was dispensed into the sample solution and the steam was switched on for 5 minutes At the end of this period the 4% boric acid containing the ammonium was titrated with 0.05 M H_2SO_4 until the neutral colour of yellowish green was observed. The same was done with a blank and all the sample solutions.

Calculation of the results (Anon, 1979)

$$\% N = \frac{14.01 \times \left(\begin{array}{c}\text{ml of titrant} \\ \text{of sample}\end{array} - \begin{array}{c}\text{ml of titrant} \\ \text{of blanks}\end{array} \right) \begin{array}{c}\text{Normality of} \\ \text{standard acid}\end{array}}{\text{g of sample} \times 10}$$

3.2.2 Determination of total phosphorus, potassium, magnesium, manganese, copper and iron in dried leaf and seed samples.

The concentrations of the following elements were detected as indicated in the seed samples. Phosphorus, spectrophotometrically. Potassium: flame-photometrically. Magnesium, manganese, copper and iron were determined by a Pye-Unicam SP9 atomic absorption spectrophotometer with an air-acetylene flame.

In each of the above techniques, the solid organic samples must be converted to liquid sample solution without the loss of any of the elements during the process.

3.2.2.1 Preparation of sample solution

Introduction:

Sample solutions of organic materials are normally prepared by one of the following two procedures for total nutrient analysis:

a) by wet digestion, and

b) by dry combustion

By the wet digestion method, the organic material is destroyed with a mixture of nitric and perchloric acids. The acids are removed by volatilisation and the soluble constituents are dissolved in hydrochloric acid. Whereas by the dry combustion method, the organic matter is destroyed by combustion and the soluble mineral constituents in the ash are dissolved in hydrochloric acid.

The wet digestion method can be dangerous if not properly conducted and therefore, the dry combustion method was used to prepare sample solutions for total P, K, Mg, Mn, Cu and Fe analysis in this project.

Materials

1. Tall heat-resistant 100 ml beakers
2. Muffle furnace, must be operated up to 450°C
3. Hydrochloric acid approximately 6M. Equal volumes of hydrochloric acid 36% m/m were mixed with deionised water.

Method (Basson and Bohmer, 1972)

0.5 g of dried sample, ground to pass a 1 mm mesh sieve was transferred into a beaker. The beaker, marked with a diamond pen was then placed in a muffle furnace which had been pre-heated to 430°C. During the first 15 minutes the door of the furnace was kept open to allow a rapid aerobic combustion. The furnace door was then shut and the sample was left for 1½ hours. On completion, the beaker was taken out and cooled. 10 ml of 6 M HCl was added to the ashed sample, and was covered with a watch glass and placed on a sand Juniper hot-plate, pre-heated to mark 3. The mixture was gently boiled, until all the acids had evaporated. Then 10 ml of deionized water was added and the beaker was heated until all the deposits had dissolved. The mixture was then transferred quantitatively into a 50 ml volumetric flask and diluted to the mark. The diluted sample solution was retained for further nutrient analysis.

3.2.2.2 Phosphorus analysis using a spectrophotometer

Principle (Anon, 1981).

The concentration of phosphorus in the sample solutions were determined spectrophotometrically as a yellow phospho-vanado-molybdate complex.

Materials

1. Ammonium molybdate-ammonium metavandate reagent. 25 g of ammonium molybdate and 1.25 g of ammonium metavandate were added to approximately 300 ml of deionized water, warmed to dissolve, cooled and diluted to 500 ml with deionized water.
2. Hydrochloric acid: approximately 5 M. 215 ml of HCl 36% m/m was diluted to 500 ml with deionized water.
3. Phosphorus stock standard solution, 1 mg/ml of phosphorus. Potassium dihydrogen orthophosphate was dried at 102°C for 1 hour and cooled in a desiccator. 0.8790 g of the dried salt was dissolved in 30 ml of deionized water and 1 ml of 36% HCl was added and the mixture was diluted to 200 ml with deionized water and one drop of toluene was added.
4. Phosphorus working standard solutions. On the day of the determination, solutions containing 0, 10, 20, 30, 40, and 50 µg per ml of phosphorus were prepared in deionized water.

Method: Preparation of standard graph:

10 ml of each phosphorus working standard solution was transferred into a separate 50 ml volumetric flask. 5 ml of 5 M HCl, and 5 ml of ammonium molybdate-ammonium metavandate reagent were added and diluted to 50 ml with deionized water. After allowing to stand for 30 minutes, the absorbance in a 10 mm optical cell at 400 nm was measured using a Unicam SP 500 spectrophotometer. A graph was constructed relating absorbance to µg of phosphorus present.

Examination of sample solution

1 ml (referred to as B) of each sample solution was transferred into a 50 ml volumetric flask and was continued as above.

Calculation of results

From the standard graph the number of micrograms of phosphorus equivalent to the absorbance of the sample was read (A) and mg P/g of sample was calculated from the following equation (Anon, 1981).

$$\text{mg P/g sample} = \frac{A \times 25}{B \times g \text{ of dried sample} \times 1000}$$

where A = sample reading in µg P from the standard graph

25 = total number of ml of sample solution

B = number of ml of sample solution used

g = weight of dried sample used to prepare sample solution

1000 = to convert from micrograms to milligrams.

3.2.2.3 Potassium analysis using a Flame-Photometer (Anon, 1981).

Principle: The concentration of potassium in the sample solution was determined with the Flame Photometer.

Materials:

1. Potassium stock standard solution. 1 mg/ml of potassium. Potassium dihydrogen orthophosphate was

dried at 102°C for 1 hour and cooled in a desiccator. 1.740 mg of the dried salt was dissolved in deionized water and 1 ml of HCl 36% m/m was added. The solution was diluted to 500 ml and one drop of toluene was added.

2. Working standard solution. Solutions containing 0, 10, 20, 30, 40 and 50 µg/ml of potassium were prepared.

Method: Preparation of standard graph

The flame photometer was set according to the manufacturer's (Corning) instructions to measure potassium emission. The working standard solutions containing 0 and 50 µg/ml were nebulized and the controls were adjusted until a steady zero and maximum readings were obtained. The intermediate working standard solutions were nebulized and a graph relating meter reading to µg/ml of potassium was constructed.

Examination of sample solutions: An appropriately diluted sample solution was nebulized and the meter reading was recorded.

Calculation of results:

The number of µg K/ml equivalent to the meter reading was read from the standard graph, called A and was converted to mg K/g of sample as follows:

$$\text{mg K/g} = \frac{A \times 25 \times D}{g \times B \times 1000}$$

where A = µg/ml of K from the standard graph

25 = total number of ml in the sample solution

D = dilution factor

g = dry weight of sample (leaf or seed)

B = number of ml of sample solution used

1000 = to convert from micrograms to milligrams of K.

3.2.2.4 Magnesium, manganese, copper and iron analysis using an Atomic Absorption Spectrophotometer

(Anon, 1981)

Principle

The concentration of these elements in the sample solution was determined by atomic absorption spectrophotometry. Addition of releasing agent to the solutions for Mg and Mn analysis eliminated interference by phosphates (Isaac, 1980).

Materials

1. Stock standard solution 1 mg/ml of the element.

   a) Magnesium. 1.0 g of magnesium metal was dissolved in 50 ml of 5 M HCl. The solution was diluted to 1 L with deionized water and stored in a polythene bottle.

   b) Manganese. 2.8770 g of dried potassium permanganate was dissolved in 500 ml of deionized water inside a 1 L volumetric flask. Hydroxyl-ammonium sulphate was added, a little at a time, until with constant swirling the solution was decolourised. The

solution then was diluted to 1 L and was allowed to stand overnight (approximately 12 hours).

c) Copper. 3.7980 g of copper nitrate was dissolved in 250 ml of deionized water and diluted to 1 L and stored in a polythene bottle.

d) Iron. 1.000 g of iron granules were dissolved in 20 ml of 5 M HCl and 5 ml of HNO_3 (S.G. 1.42). This was diluted to 1 L with deionized water and stored in a polythene bottle.

2. Releasing agent. 60 g of strontium chloride ($SrCl_2.6H_2O$) dissolved in approximately 60% m/m $HClO_4$, was added and the mixture diluted to 1 L with deionized water.

3. Working standard solutions Solutions containing:

* Magnesium: 0, 0.2, 0.4, 0.6, 0.8 and 1.0 µg/ml.
* Manganese: 0, 0.25, 0.5, 1.0, 2.5 and 5.0 µg/ml.

Copper: 0, 0.2, 0.4, 0.8, 1.2 and 2.0 µg/ml. and

Iron: 0, 0.8, 1.6, 2.4, 3.2 and 4.0 µg/ml.

* = 10% v/v of releasing agent was added.

Method: Preparation of standard graph

The atomic absorption spectrophotometer was set according to the manufacturers instructions to measure the following emission from hollow cathode lamps at spectral bandwidth of:

	emission	bandwidth
Magnesium	285 nm	0.6 nm
Manganese	279.5 nm	0.2 nm
Copper	324.8 nm	0.6 nm
Iron	248.3 nm	0.5 nm

The working standard solutions containing the lowest and highest µg/ml of the elements were nebulized and the controls were adjusted until a steady zero and suitable maximum readings were obtained. The intermediate standard solutions were nebulized and graphs relating meter readings to µg/ml of the elements in all standard solutions were constructed.

Examination of sample solution

1 ml of sample solutions of Mg, Mn and Cu were measured into a 100 ml volumetric flask.10 ml of releasing agent was added for Mg and Mn analysis and all were diluted to 100 ml with deionized water. The diluted solutions were nebulized and the meter readings recorded. Sample solutions for Fe were nebulized without dilution and addition of releasing agent and the meter readings were recorded.

Calculation of results

From the standard graphs the number of µg/ml of element equivalent to the meter readings (A) were read, and were converted to µg/g as follows:

$$\mu g/g = \frac{A \times 25 \times D}{g \text{ of sample}}$$

where A = µg/g reading from the graph

25 = total no. of ml in the sample solution

D = dilution factor

g = weight of dried sample (leaf or seed).

3.3 Materials and Methods for Seed Quality and Vigour tests

3.3.1 Standard Germination Test

Introduction

The standard germination test is internationally accepted by farmers, seedsmen and research workers and allows the germination percentage of a given seed lot to be determined according to the international rules for seed testing (Anon, 1976a).

Procedure

The environmental conditions for this test were according to ISTA specification, but in experiments 1 and 2 the number of seeds was modified because of the relatively low seed yield in some treatments.

All the treatments in experiments 1 and 2 were tested with samples of 25 seeds, replicated twice, whereas in experiments 3 and 4, the test ws conducted with samples of 50 seeds, replicated three times. In all cases the seeds were selected randomly. The seeds were sown 15 mm deep in 150 mm diameter aluminium germination dishes containing pure, sterilized fine silver sand (Anon, 1977), for experiments 1 and 2 and in universal seed germination compost in half seed trays for experiments 3 and 4.

After sowing the containers were watered and placed in a growth cabinet at 20°C and not less than 95% relative humidity. Light from the fluorescent lamps was provided for 16 hours in each 24 hour cycle. No interim counts of germination were made in experiments 1 and 2, but a 4 days interim count was made in experiments 3 and 4. In all cases the test was completed in 8

days and the seedlings were evaluated and put into the following categories:

1. Normal seedlings
2. Abnormal seedlings
3. Fresh seeds
4 Hard seeds
5 Dead seeds

According to the description stated in Anon (1977), the total number in the categories 1 and 2 is the percentage germination.

3.3.2 Conductivity test

Introduction

The conductivity test has been proposed as a vigour test because less vigorous seeds were observed to be frequently infected by fungi. This infection was considered a result of increased exudation of sugars and other metabolites (Matthews and Bradnock, 1968).

The seed sample to be tested is soaked in deionized water and the amount of inorganic salts in the subsequent solution is measured by the electrical conductivity test. This test has been further developed by the Processors and Growers Research Organisation (P.G.R.O., 1981), and is currently accepted in the U.K. as an official test for pea seed, in addition to the germination test, to be sown by commercial growers (McKay, 1970).

Procedure

The procedures which have been standardised by P.G.R.O. (1981) for peas were used but the seed sample number was

modified, because of the low number of seeds harvested from some nutrient treatments. Two seed samples of 25 were taken randomly and weighed to two decimal places from all the treatments in experiments 1 and 2 whereas three samples of 50 seeds were used in experiments 3 and 4. The samples were then transferred to 400 ml conical flasks containing 125 ml of deionized water in experiments 1 and 2 and 250 ml of deionized water in experiments 3 and 4. The deionized water had been kept at 20°C for 24 hours prior to use. The containers were then covered to prevent evaporation and entry of foreign matter. A separate container of deionized water without seeds was prepared (blank sample). All containers were kept at 20°C for 24 hours. After removing the seeds with a coarse plastic sieve, the reading (in micro-seimens, μs) was taken with the 'blank' container and of each of the solutions, using the electrical conductivity meter model P310 with PE10 platinum block dip-type cell. The blank was subtracted from all the sample readings and the weight of the dry seed was divided into the corrected conductivity result for each of the replicated seed samples. The figures obtained represent vigour grades in μs per g.

3.3.3 Cold test

Principle

The cold test is a seed vigour test, which imposes stress on germinating seedlings by subjecting them to microorganisms and to a cool moist soil environment. Vigorous seeds and seedlings are able to resist the organisms to a greater extent than the weaker ones.

Introduction

The cold test procedure consists of two stages. The first stage is to sow the seeds in moist, unsterilized soil and allowing them to remain in an incubator at a relatively low temperature (i.e. 5-10°C) for one week. The second stage starts by transferring the germinating containers to a more favourable temperature (i.e. 20-30°C) and high light intensity. Low temperature retards the physiological activities of the germinating seed and thus predisposes them to attack by soil organisms (Perry, 1981).

Procedure

In this study an attempt was made to use the cold test to compare the vigour of pea seed lots obtained from plants grown under different nutrient treatments. The procedure followed was similar to that described by Woodstock (1976) but with slight modification. Two replicates of 50 seeds in Experiment 1, 25 seeds in Experiment 2 and 3 replicates of 100 seeds in Experiments 3 and 4 were sown. The seeds from Experiments 1 and 2 were sown in aluminium dishes (150 mm diameter) and from Experiments 3 and 4 in half seed trays (22 mm x 16 mm x 6 mm). All the germination dishes contained soil from the Claverton Down Field station, previously cropped with sweet corn in the case of the cold test for the first experiment, cabbage for the second experiment and peas for the third and fourth experiments. The moisture content of the soil and its water holding capacity were determined as described by Bunt (1976), before sowing the seeds. The amount of water needed to bring the moisture content to 70% of its water holding capacity of the germinating medium was calculated by using the following formula as described by Fiala (1981).

$$W = \frac{B \times (100-F) \times WK \times P}{106} - \frac{B \times F}{100}$$

where W = required quantity of water (cm^3) which must be added to the soil to bring the moisture content to a specific water holding capacity (e.g. 70%)

B = weight of moist soil (g)

F = percentage moisture content of moist soil on a weight basis

WK = maximum water holding capacity as percentage of dry soil

P = required percentage of water holding capacity (i.e. 70%).

After watering, the germination dishes were placed in a growth chamber at 10°C for 7 days. At the end of this period the trays were transferred into a greenhouse with a temperature ranging from 27°C maximum to 15°C minimum. Counts of seedlings were made two weeks after transfer into the glasshouse. Total dry weight of the seedlings were also recorded.

3.3.4 Measurement of Adenosine Triphosphate (ATP) as a vigour test

Introduction

ATP is the biological energy needed for every biosynthetic pathway, as well as biological work, e.g. movement, transport, assembly of organelles and repairs. Since ATP is required for endergonic reactions including biosynthesis regulations and protein synthesis during germination processes, a measure of ATP pool size reflecting its synthesis and availability can be used as a biochemical index of growth potential or seedling vigour.

The following experiment was designed to determine the relationship of ATP concentration after 24 hours imbibition to germination and seedling vigour of the seeds obtained from experiments 2, 3 and 4 produced under different nutrient regimes. However, it was only possible to perform the test with experiment 2 as the equipment necessary for the analysis was not available in the following year, as it was on loan from Bristol University.

Principle

The ATP assay has been described by St. John (1970). The principle of ATP assay of the extraction is based on the following reactions (McDaniel, 1969).

$$\underset{\text{(Luciferase)}}{E} + \underset{\text{(Luciferin)}}{LH_2} + ATP \underset{\text{Arsenate}}{\overset{Mg}{\rightleftharpoons}} \underset{\substack{\text{(Lucifeyl adenylate complex)}}}{E - LH_2\text{-}AMP} + \underset{\text{(Pyro-phosphate)}}{PP_1}$$

then:

$$E - LH_2\text{-}AMP + O_2 \longrightarrow E + \underset{\text{(oxidized Luceferin)}}{L{:}O} + AMP + Light$$

The light produced in the second reaction is proportional to ATP quantity in the first reaction when Luciferase and Luciferin are not limiting.

Procedure

The ATP extraction and buffering procedures were similar to those used by Ching and Danielson (1972) and the ATP assay is the one developed and used by St. John (Styer, Cantliffe and Hall, 1980).

To obtain seed extract for ATP analysis, four replicate samples of 5 seeds were randomly selected from each treatment batch, weighed and wrapped in two layers of "Whatman Number one" filter paper moistened with distilled water inside a petri dish and were imbibed for 24 hours in an incubator set at 20°C with 12 hours lighting. After imbibition, seeds were crushed in a marble mortar and pestle and placed in a test tube with 10 ml of boiling distilled water. Aluminium foil capped tubes were held at 100°C for 10 minutes and then cooled in an ice bath.

5 ml of the extract was diluted with 5 ml of buffer containing 0.05 M N-2-hydroxyethylpiperazine-N'-2-ethane sulfonic acid (HEPES), pH 7.5, and 0.05 M magnesium acetate.

Freeze-dried firefly extract containing Luciferin-Luciferase was reconstituted by adding 5 ml of ice-cold distilled water. The enzyme preparation containing 0.05 M potassium arsenate and 0.02 M magnesium sulphate at pH 7.4 was incubated at 4°C for 24 hours to deplete endogenous ATP.

Four samples of 1 ml from the seed extract were pipetted into small glass cuvettes. 0.1 ml of the enzyme preparation was injected into the sample cuvette and peak height of light production was immediately recorded using a Spectro-plus in fluorescence mode (MSE Scientific Instruments). The ATP concentrations corresponding to the unknown peak height was read from a standard curve and expressed as nmole ATP per gram seed weight.

Materials

1. Luciferin-Luciferase enzyme solution (Sigma Chemical Company. Catalogue number FLE 50).
2. ATP standard solution

   Adenosine 5'-triphosphate (Sigma Chemical Company, Catalogue Number FFATP. MW 623.2). 0, 0.1, 0.2, 0.3 and 0.4 nM working solutions were prepared.
3. Buffer solution.

   Containing 0.05 M N-2-hydroxyethyl-piperazine-N'-2-ethane sulfonic acid (HEPES) (Sigma Chemical Company. Catalogue number N-3375 MW 238.3), pH 7.5, and 0.05 M magnesium acetate (BDH, Analar, no. 10148, MW = 214.46).

4. RESULTS

4.1 Plant Growth

4.1.1 Experiment 1: Plant Dry Weight (g per plant)

The dry weight of plants in each treatment were determined after harvesting in order to examine the effect of N, P and K nutrition levels on the vegetative plant.

Total nutrient levels (mg per plant)	Plant dry weight (g)	Total nutrient levels (mg per plant)	Plant dry weight (g)	Total nutrient levels (mg per plant	Plant dry weight
N_1 = 100	2.26	P_1 = 50	2.18	K_1 = 40	2.31
N_2 = 150	2.20	P_2 = 70	2.19	K_2 = 60	2.40
N_3 = 300	2.46	P_3 = 140	2.45	K_3 = 120	2.39
N_4 = 500	2.53	P_4 = 210	2.63	K_4 = 180	2.35

Significance levels:

N: 1% N x P: N.S.

P: 0.1% N x K: N.S. N x P x K: NS

K: N.S. P x K: N.S.

L.S.D. (N,P,K) = 0.223 (NxP,PxK,NxK) = 0.445 (N x P x K) = 0.891

Table 11. The effect of N, P and K nutrition levels on plant dry weight in experiment 1.

From the analysis of variance presented in Table 11, it can be seen that only levels of N and P have significantly affected the plant dry weight at 1.0% and 0.1% significance level.

As shown in Figure 11, the plant dry weight increased with increasing levels of N after an initial decrease from N_1 to N_2 and it also increased with increasing levels of P in this experiment in the order of $N_4 > N_3 > N_1 > N_2$ and $P_4 > P_3 > P_2 > P_1$.

Figure 12 shows the effect of N and P interaction on plant dry weight.

4.1.2 Experiment 2: Plant dry weight (g per plant)

The dry weight of the plants in each treatment were determined after harvesting in order to examine the effect of N, and P nutrition levels on the vegetative plant.

Total nutrient levels (mg per plant)	Plant dry weight (g per plant)	Total nutrient levels (mg per plant)	Plant dry weight (g per plant)
N_1 = 100	1.68	P_1 = 25	1.66
N_2 = 1000	2.29	P_2 = 250	2.15
		P_3 = 500	2.20
		P_4 = 1000	1.93

Significance levels:

N:	0.1%	P: 1.0%	N x P: 1.0%
5% LSD	N: 0.223	P: 0.315	N x P: 0.445

Table 12. The effect of N and P nutrition levels on plant dry weight in Experiment 2.

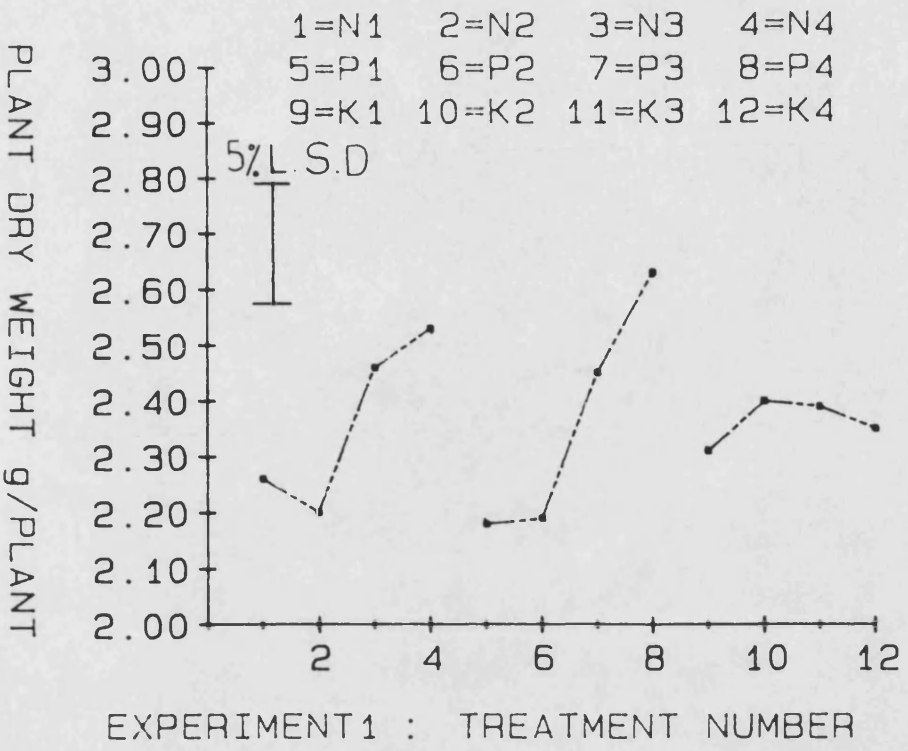

Figure 11. The main effect of N, P and K mineral nutrition levels on plant dry weight.

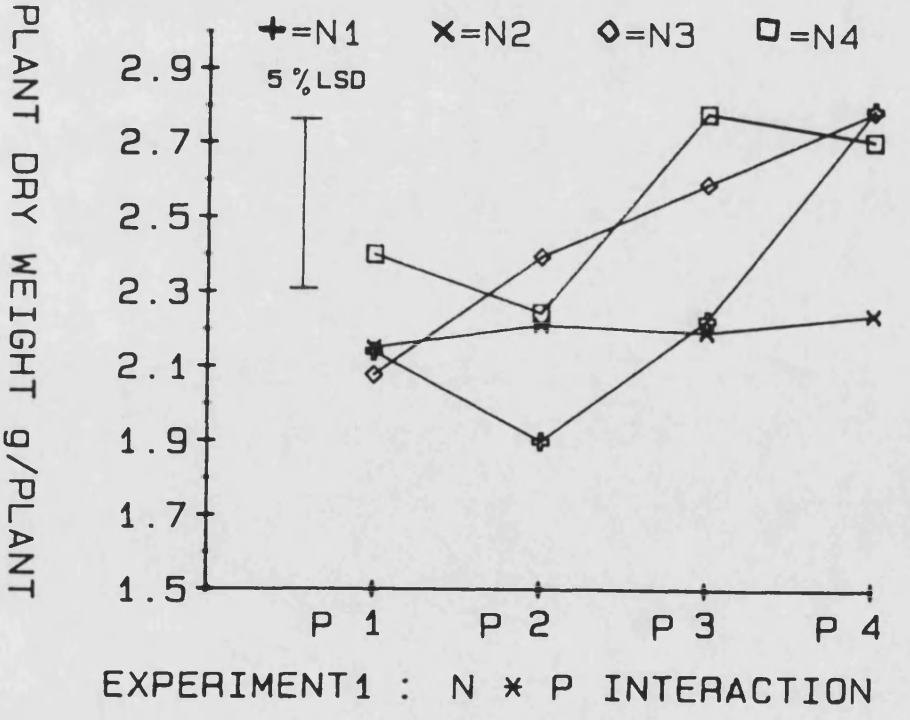

Figure 12. The effect of N and P interaction on plant dry weight.

From the analysis of variance presented in Table 12 it can be seen that levels of N, P and their interaction N x P have significantly affected the plant dry weight at 0.1%, 1.0% and 1.0% levels respectively.

As shown in Figure 13 the plant dry weight increased with increasing N levels and that P levels had a similar effect up to P_3 and declined from P_3 to P_4 as indicated in the order of $N_1 < N_2$ and $P_1 < P_2 < P_3 > P_4$.

Figure 14 shows the effect of N and P interaction on plant dry weight. The highest plant dry weight was achieved by the combination N_2P_3 (2.77 g) and the lowest by N_1P_1 (1.47 g).

4.1.3 Experiment 3: Plant dry weight (g per plant)

The dry weight of the plants in each treatment were determined after harvesting in order to examine the effect of N, P and K nutrition levels on the vegetative plant. From the analysis of variance presented in Table 13, it can be seen that the plant dry weight per plant was not significantly affected by N, P K or any of their interactions in this experiment.

Figure 15 shows the main effect of N, P and K nutrition levels on plant dry weight.

Figure 16 shows the effect of N and P interaction on plant dry weight.

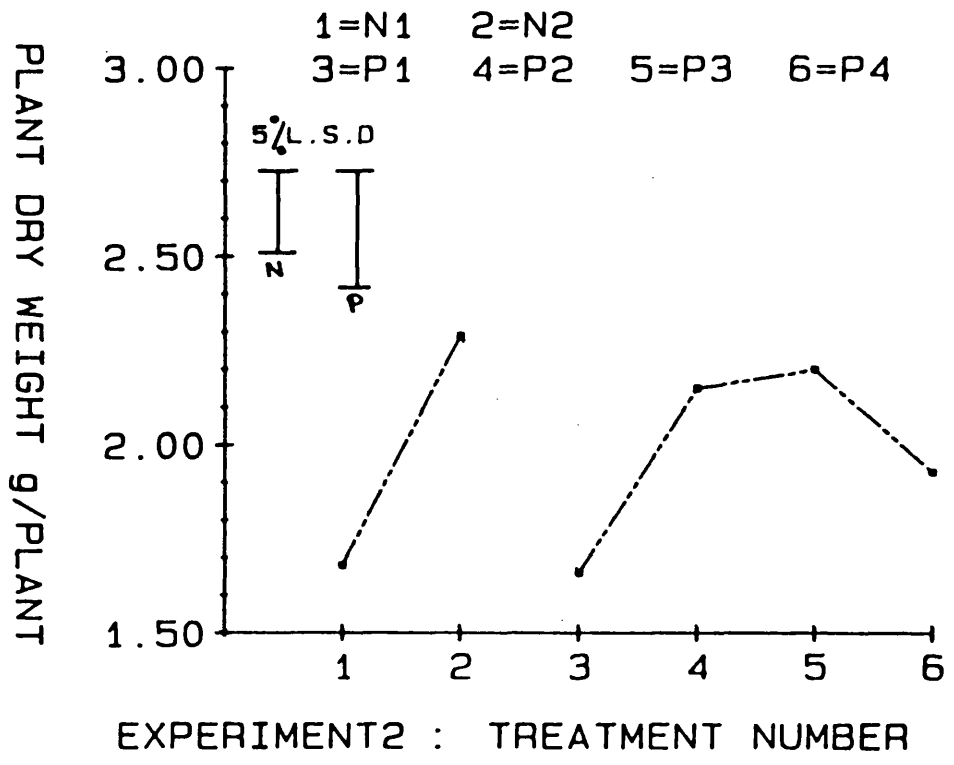

Figure 13. The main effect of N and P mineral nutrition on plant dry weight.

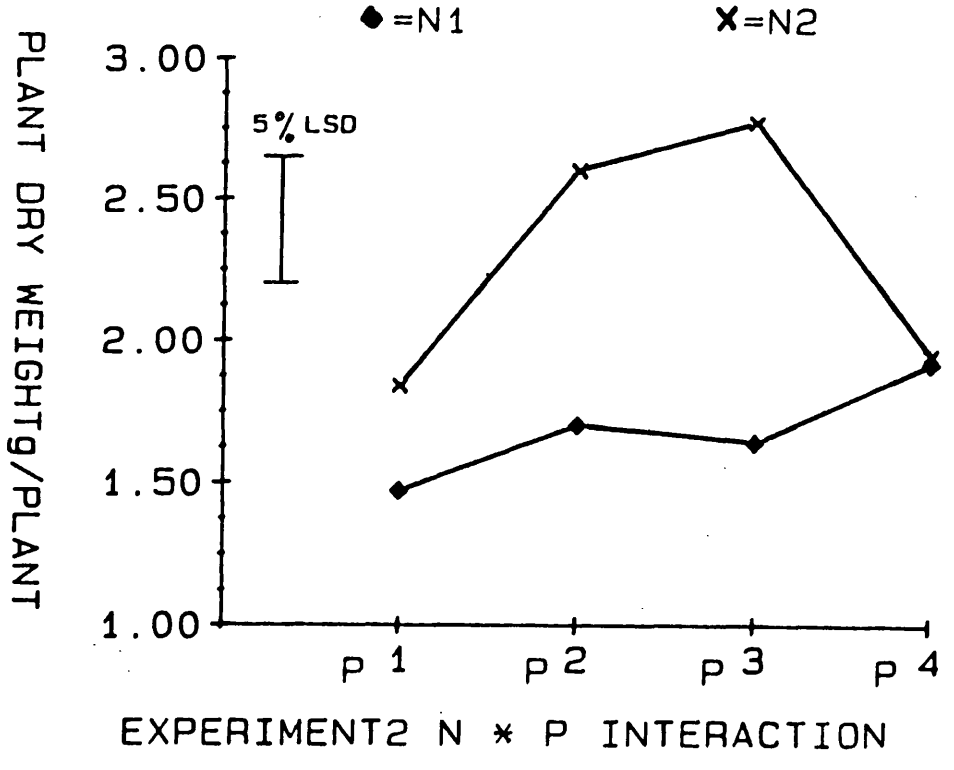

Figure 14. The effect of the N and P interaction on plant dry weight.

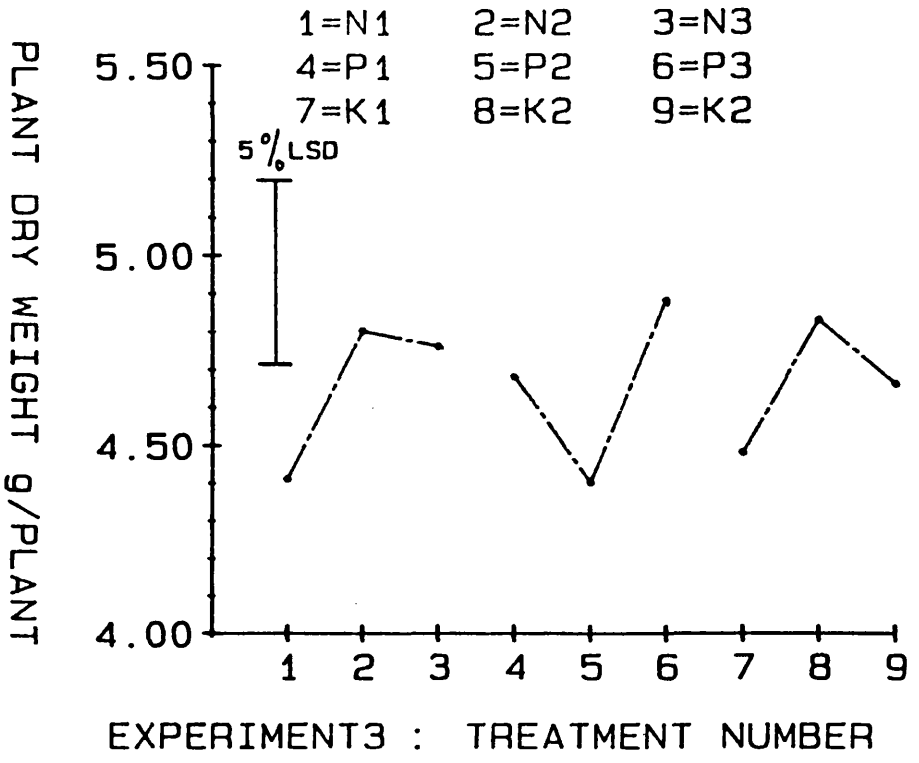

Figure 15. The main effect of N, P and K mineral nutrition levels on plant dry weight.

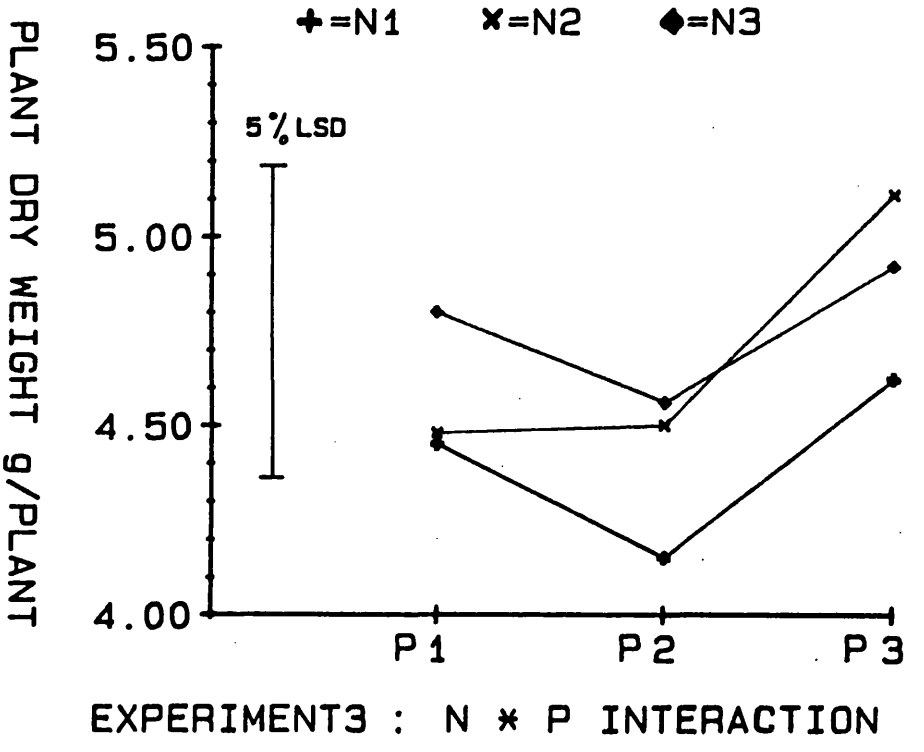

Figure 16. The effect of N and P interaction on plant dry weight.

Total nutrient levels (kg per plant)	Plant dry weight (g)	Total nutrient levels (kg per plant) (g)	Plant dry weight (g)	Total nutrient levels (kg per plant	Plant dry weight
$N_1 = 0$	4.41	$P_1 = 0$	4.68	$K_1 = 0$	4.48
$N_2 = 25$	4.80	$P_2 = 50$	4.40	$K_2 = 25$	4.83
$N_3 = 75$	4.76	$P_3 = 150$	4.88	$K_3 = 75$	4.66

Significance levels:

N: N.S. N x P: N.S.

P: N.S. N x K: N.S. N x P x K: NS

K: N.S. P x K: N.S.

L.S.D.5%

(N,P,K) = 0.481 (NxP,PxK,NxK) = 0.833 (N x P x K) = 1.442

Table 13. The effect of N, P and K nutrition levels on plant dry weight in Experiment 3.

4.1.4 Experiment 4: Plant dry weight (g per plant)

The dry weights of the 36 plants in each treatment were determined after harvesting in order to examine the effect of the N and K nutrition levels on the vegetative plant. From the analysis of variance, presented in Table 14, it can be seen that only N levels affected the plant dry weight significantly at 0.1% level. Neither K nor the interaction N x K had a significant effect.

As shown in Figure 17, plant dry weight increased with increasing levels of N in this experiment, in the order of $N_1 \approx N_2 < N_3 < N_4$.

Total nutrient levels (mg per plant)	Plant dry weight (g per plant)	Total nutrient levels (mg per plant)	Plant dry weight (g per plant)
N_1 = 0	2.90	K_1 =0	3.26
N_2 = 100	2.87	K_2 = 50	3.73
N_3 = 500	3.69	K_3 = 250	3.44
N_4 = 1000	4.33	K_4 = 500	3.36

Significance levels:

N: 0.1% P: N.S. N x K: N.S.

5% LSD = 0.461

Table 14. The effect of N and K nutrition levels on plant dry weight in Experiment 4.

Figure 18 shows the effect of N and K interaction on the plant dry weight. The highest plant dry weight was achieved by the combination N_4K_3 (4.76 g) and the lowest by N_2K_3 (2.21 g).

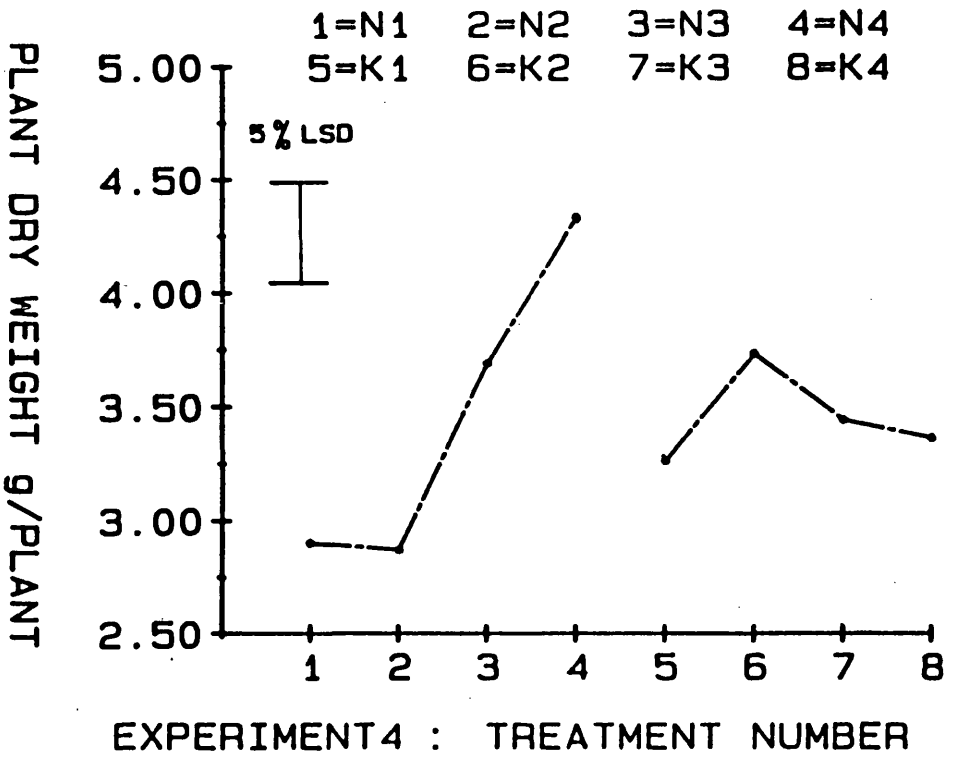

Figure 17. The main effect of N and K mineral nutrition levels on plant dry weight.

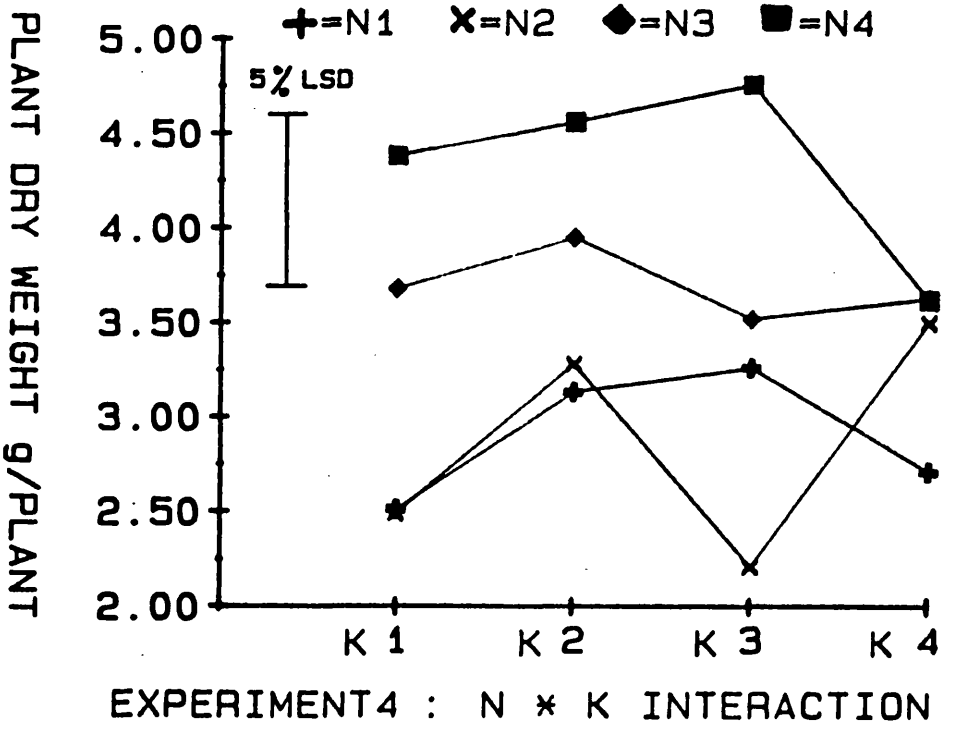

Figure 18. The effect of N and K interaction on plant dry weight.

4.2 Seed yield

4.2.1.1 Experiment 1: Number of pods per plant

The numbers of pods harvested from the plants in each treatment were recorded during the harvest in order to examine the effect of N, P and K nutrition levels on the number of pods produced per plant.

Total nutrient levels (mg per plant)	Number of pods	Total nutrient levels (mg per plant)	Number of pods	Total nutrient levels (mg per plant	Number of pods
N_1 = 100	4.17	P_1 = 50	3.89	K_1 = 40	4.43
N_2 = 150	4.36	P_2 = 70	4.12	K_2 = 60	4.58
N_3 = 300	4.46	P_3 = 140	4.68	K_3 = 120	4.28
N_4 = 500	4.39	P_4 = 210	4.69	K_4 = 180	4.08

Significance levels:

N: N.S. N x P: N.S.

P: 0.1% N x K: N.S. N x P x K: NS

K: 5.0% P x K: N.S.

L.S.D. (N,P,K) = 0.339 (NxP,PxK,NxK) = 0.678 (N x P x K) = 1.356

Table 15. The effect of N, P and K nutrition levels on the number of pods produced per plant in Experiment 1.

From the analysis of variance presented in Table 15, it can be seen that only P and K levels significantly affected the pod number at 0.1% and 5.0% significant levels respectively.

As shown in Figure 19, the number of pods per plant increased by increasing levels of P and decreased by increasing levels of K after an initial increase from K_1 to K_2 in this experiment and in the order of $P_4 > P_3 > P_2 > P_1$ and $K_2 > K_1 > K_3 > K_4$.

Figure 20 shows the effect of P and K interaction on pod number produced by a plant.

4.2.1.2 Experiment 1: Pod dry weight (g per plant)

The dry weights of pods harvested from the plants in each treatment were recorded after seed extraction in order to examine the effect of N, P and K nutrition levels on pod dry weight.

Total nutrient levels (mg per plant)	Pod dry weight (g)	Total nutrient levels (mg per plant) (g)	Pod dry weight (g)	Total nutrient levels (mg per plant	Pod dry weight (g)
N_1 = 100	0.714	P_1 = 50	0.739	K_1 = 40	0.751
N_2 = 150	0.756	P_2 = 70	0.737	K_2 = 60	0.775
N_3 = 300	0.784	P_3 = 140	0.789	K_3 = 120	0.735
N_4 = 500	0.788	P_4 = 210	0.779	K_4 = 180	0735

Significance levels:

N: N.S. N x P: N.S.

P: N.S. N x K: N.S. N x P x K: NS

K: N.S. P x K: N.S.

L.S.D. (N,P,K) = 0.064 (NxP,PxK,NxK) = 0.128 (N x P x K) = 0.256

Table 16. The main effect of N, P and K mineral nutrition levels on dry weight of pods produced by a plant in Experiment 1.

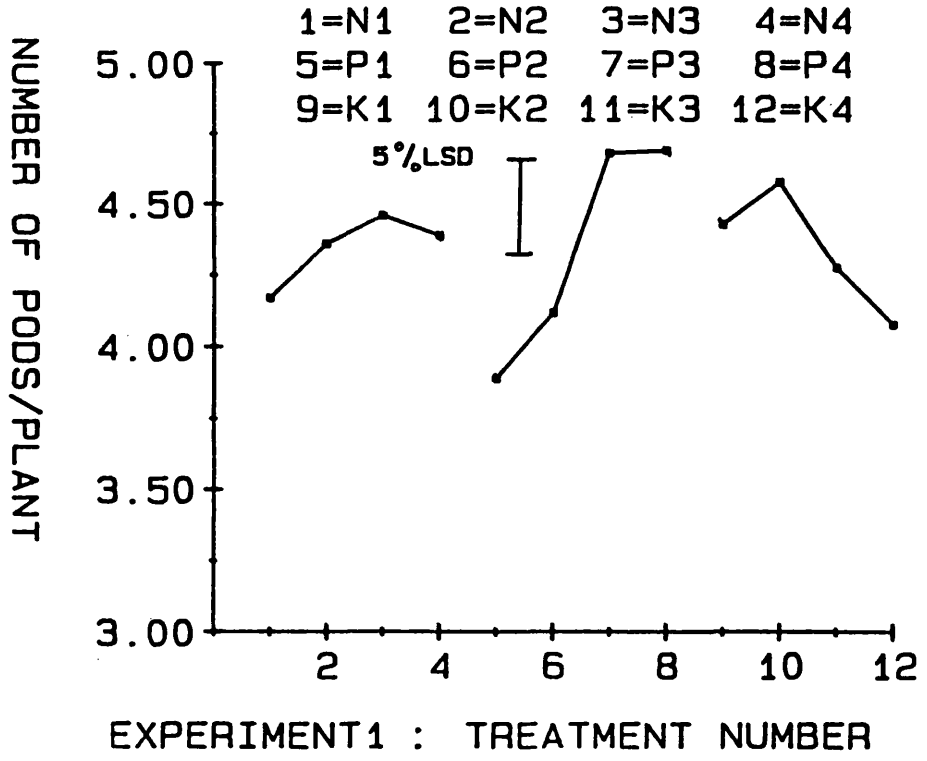

Figure 19. The main effect of N, P and K mineral nutrition levels on the number of pods produced by a plant.

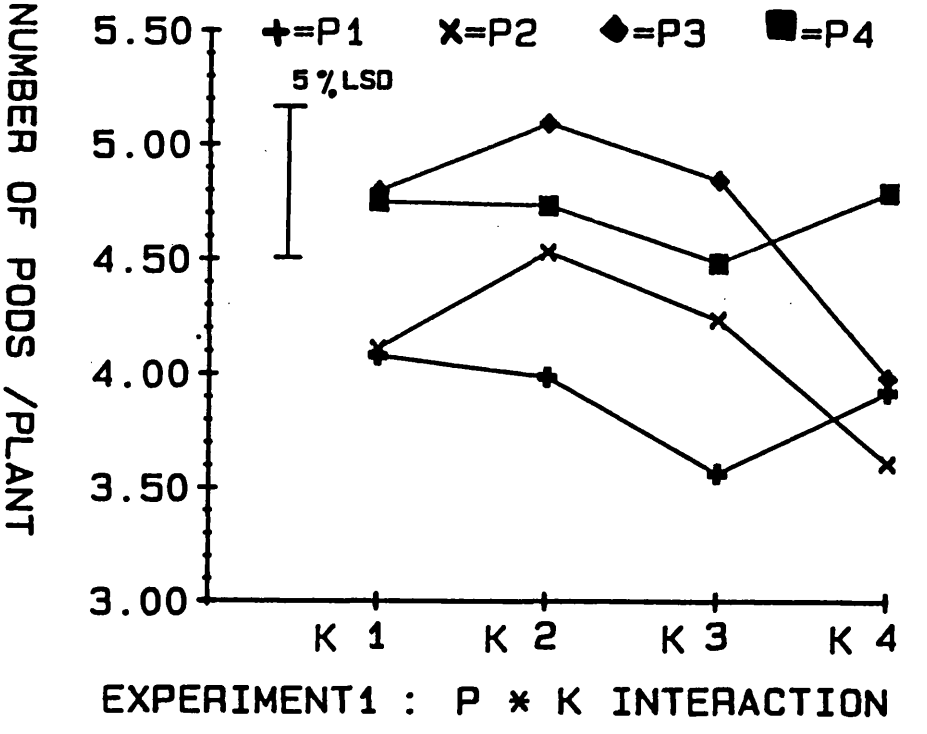

Figure 20. The effect of P and K interaction on pod number per plant.

The analysis of variance presented in Table 16, shows that none of the nutrient levels had a significant effect on pod dry weight per plant in this experiment.

Figure 21 shows the main effect of N, P and K levels on pod dry weight per plant.

Figure 22 shows the effect of N and P interaction on pod dry weight per plant.

4.2.1.3 Experiment 1: Number of seeds per plant

The number of seeds from plants in each treatment were recorded during pod shelling in order to examine the effect of N, P and K nutrition levels on seed yield in terms of seed number.

Total nutrient levels (mg per plant)	Seed number	Total nutrient levels (mg per plant)	Seed number	Total nutrient levels (mg per plant	Seed number
N_1 = 100	16.03	P_1 = 50	14.65	K_1 = 40	15.93
N_2 = 150	16.05	P_2 = 70	15.58	K_2 = 60	17.13
N_3 = 300	17.38	P_3 = 140	17.55	K_3 = 120	16.58
N_4 = 500	16.30	P_4 = 210	18.03	K_4 = 180	16.13

Significance levels:

N: N.S. N x P: N.S.

P: 0.1% N x K: N.S. N x P x K: NS

K: N.S. P x K: 5.0%

L.S.D. (N,P,K) = 1.296 (NxP,PxK,NxK) = 2.593 (N x P x K) = 5.186

Table 17. The effect of N, P and K nutrition levels on number of seeds produced per plant in Experiment 1.

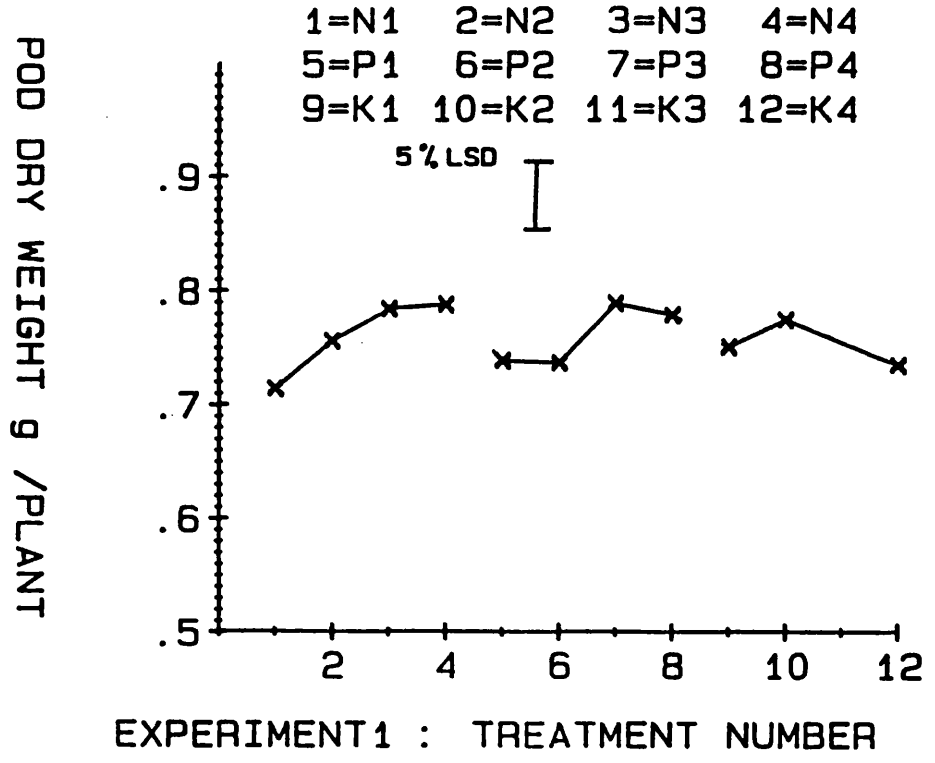

Figure 21. The main effect of N, P and K mineral nutrition levels on pod dry weight per plant.

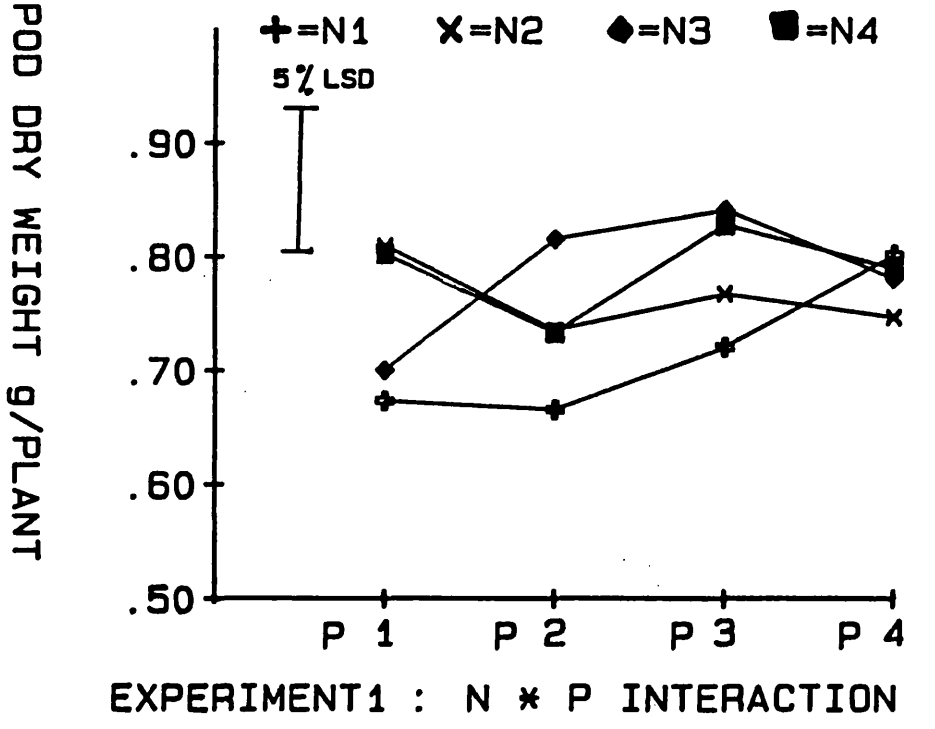

Figure 22. The effect of N and P interaction on pod dry weight per plant.

From the analysis of variance presented in Table 17, it can be seen that only levels of P and the P and K interaction significantly affected the seed number at 0.1% and 5.0 significance level respectively. As shown in Figure 23, the number of seeds produced per plant increased with increasing levels of P in this experiment and in the order of $P_4 > P_3 > P_2 > P_1$.

Figure 24 shows the effect of P and K interaction on the number of seeds produced per plant. The highest number was achieved by the combination P_4K_4 (19.45) and the lowest by P_1K_3 (13.45).

4.2.1.4 Experiment 1: Seed dry weight (g per plant)

The dry weight of the seeds from the plants in each treatment were recorded when the seeds' moisture content were at 11 ± 0.5% in order to examine the effect of N, P and K nutrition levels on seed yields. From the analysis of variance presented in Table 18, it can

Total nutrient levels (mg per plant)	Seed weight (g)	Total nutrient levels (mg per plant)	Seed weight (g)	Total nutrient levels (mg per plant	Seed weight
N_1 = 100	3.465	P_1 = 50	3.428	K_1 = 40	3.760
N_2 = 150	3.575	P_2 = 70	3.380	K_2 = 60	3.730
N_3 = 300	4.183	P_3 = 140	4.000	K_3 = 120	3.730
N_4 = 500	3.648	P_4 = 210	4.060	K_4 = 180	3.660

Significance levels:

N: 5% N x P: N.S.

P: 1.0% N x K: N.S. N x P x K: NS

K: N.S. P x K: N.S.

L.S.D. (N,P,K) = 0.503 (NxP,PxK,NxK) = 1.01 (N x P x K) = 2.01

Table 18. The effect of N, P, K levels on seed dry weight in Experiment 1.

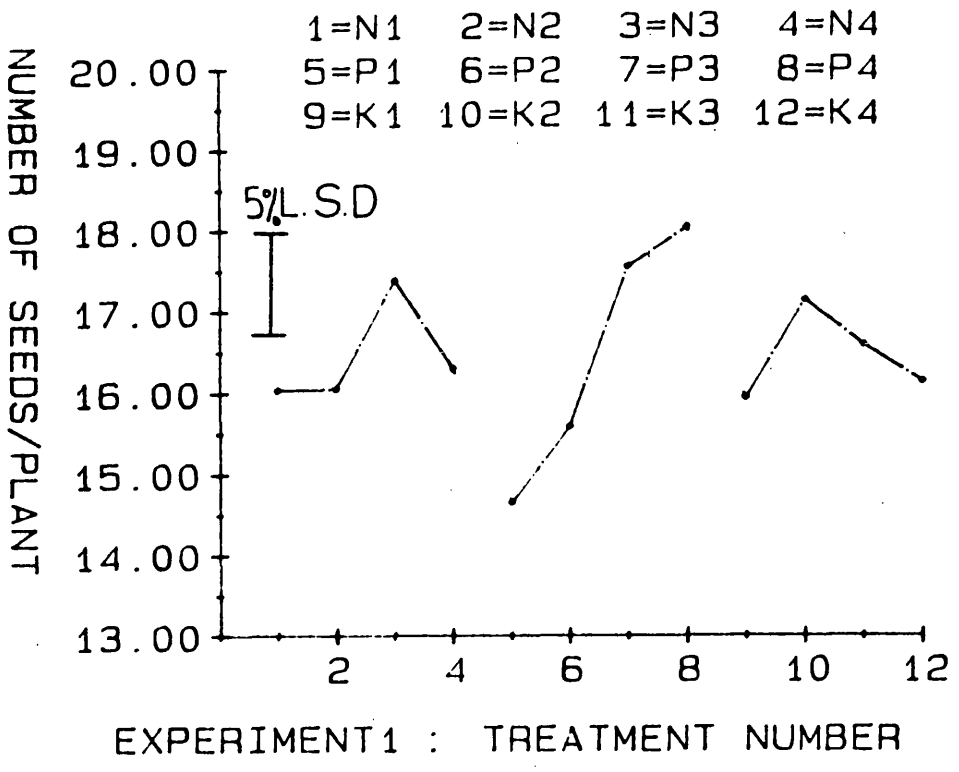

Figure 23. The main effect of N, P and K mineral nutrition levels on the number of seeds produced per plant.

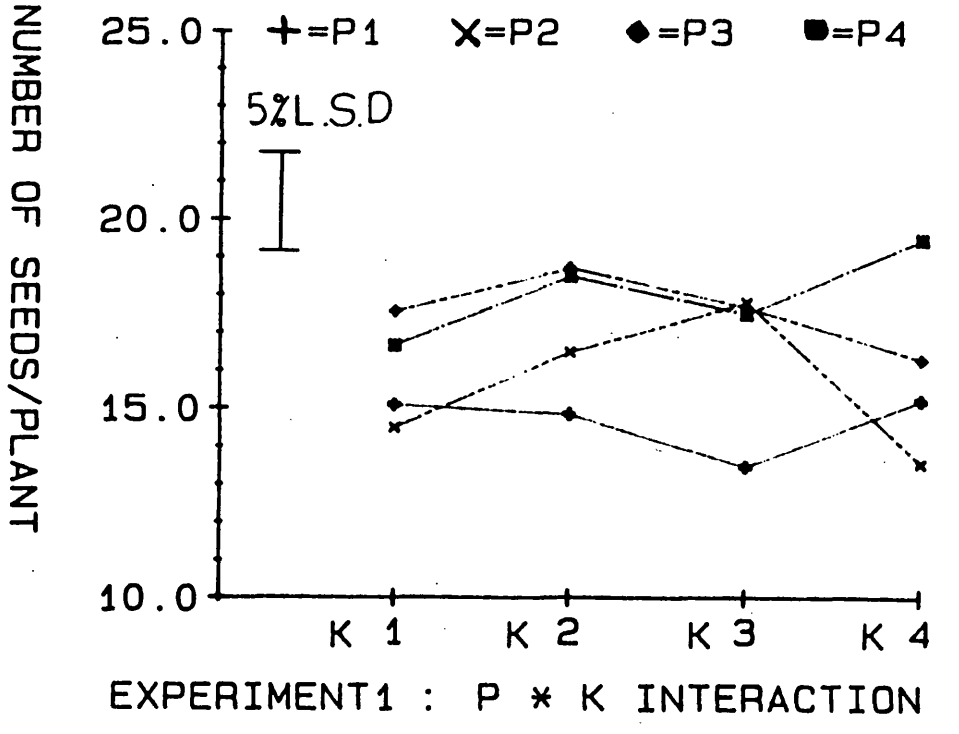

Figure 24. The effect of P and K interaction on the seed number produced per plant.

be seen that only levels of N and P significantly affected the dry weight of the seeds produced by a plant, at 5.0% and 1.0% significance levels respectively.

As shown in Figure 25, the seed dry weight increased with increasing levels of N up to N_3 and declined from N_3 to N_4 and it also increased with increasing levels of P after an initial slight decrease from P_1 to P_2 in this experiment, in the order of $N_3 > N_4 > N_2 > N_1$ and $P_4 > P_3 > P_1 > P_2$.

Figure 26 shows the effect of N and P interaction on seed dry weight per plant.

4.2.1.5 Experiment 1: Number of seeds per pod

The number of seeds per pod was calculated by dividing the total seed number by total pod number in each treatment in order to examine the effect of N, P and K nutrition levels on seeds set per pod. From the analysis of variance presented in Table 19 it can be seen that the levels of N, K and the interaction P K and N x P x K significantly affected the number of seeds per pod at 5.0%, 0.1%, 1.0% and 1.0% significance levels respectively.

As shown in Figure 27 the number of seeds per pod was affected by the levels of N in the order of $N_3 > N_4 > N_1 > N_2$ and that it increased by increasing levels of K in this experiment and in the order of $K_4 > K_3 > K_2 > K_1$.

Figure 28 shows the effect of P and K interaction on the number of seeds per pod. The highest number was achieved by the combination P_2K_3 (4.23) and the lowest by P_4K_1 (3.49).

In the three way N x P x K interaction the highest number was achieved by the combination $N_3P_2K_3$ (4.5) and the lowest by $N_2P_4K_3$ (2.80).

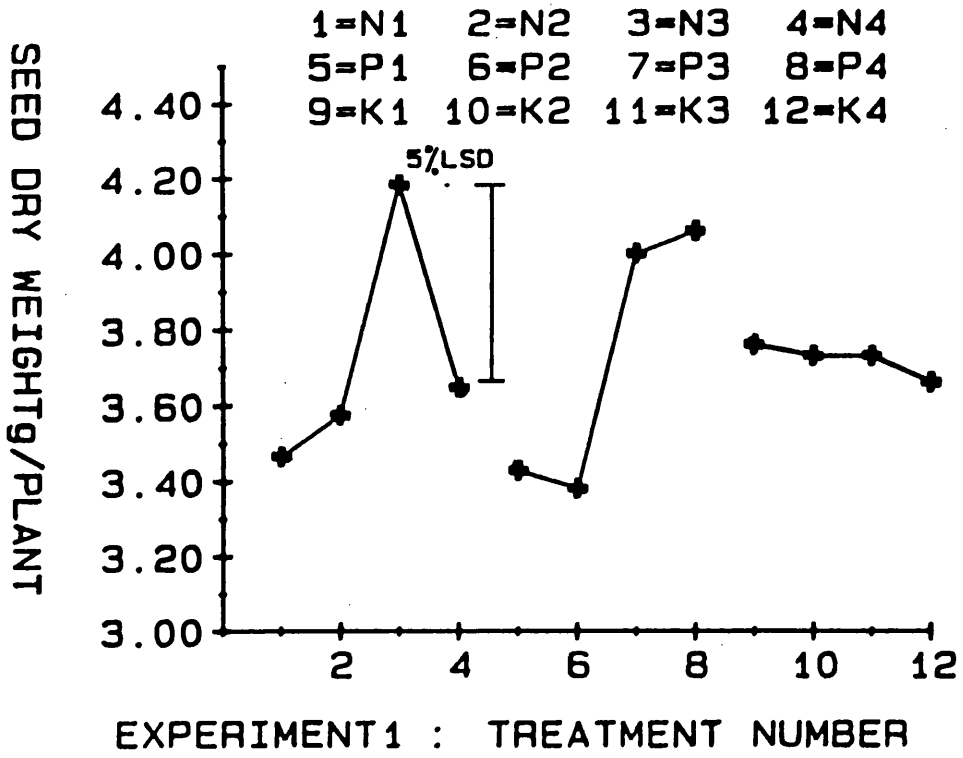

Figure 25. The main effect of N, P and K mineral nutrition levels on seed yield as determined by seed dry weight per plant.

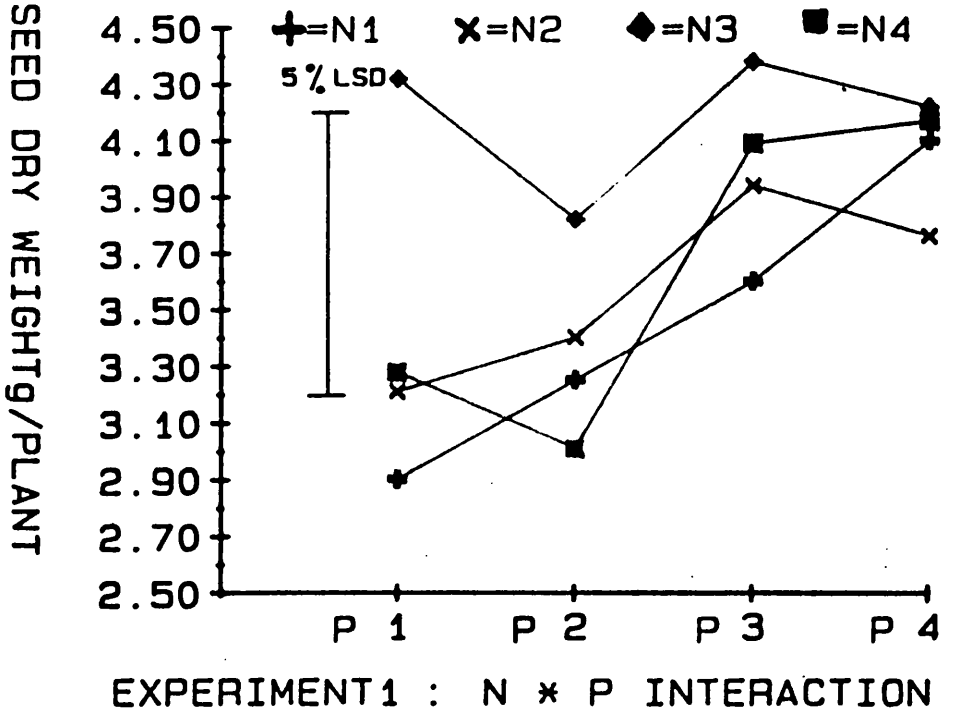

Figure 26. The effect of N and P interaction on seed dry weight per plant.

Total nutrient levels (mg per plant)	Seeds per pod	Total nutrient levels (mg per plant)	Seeds per pod	Total nutrient levels (mg per plant	Seeds per pod
N_1 = 100	3.88	P_1 = 50	3.81	K_1 = 40	3.61
N_2 = 150	3.68	P_2 = 70	3.79	K_2 = 60	3.77
N_3 = 300	3.93	P_3 = 140	3.77	K_3 = 120	3.87
N_4 = 500	3.74	P_4 = 210	3.87	K_4 = 180	3.97

Significance levels:

N: 5% N x P: N.S.

P: N.S. N x K: N.S. N x P x K: 1.0%

K: 0.1% P x K: 1.0%

L.S.D. (N,P,K) = 0.175 (NxP,PxK,NxK) = 0.351 (N x P x K) = 0.701

Table 19. The effect of N, P and K nutrition levels on the number of seeds produced per pod in experiment 1.

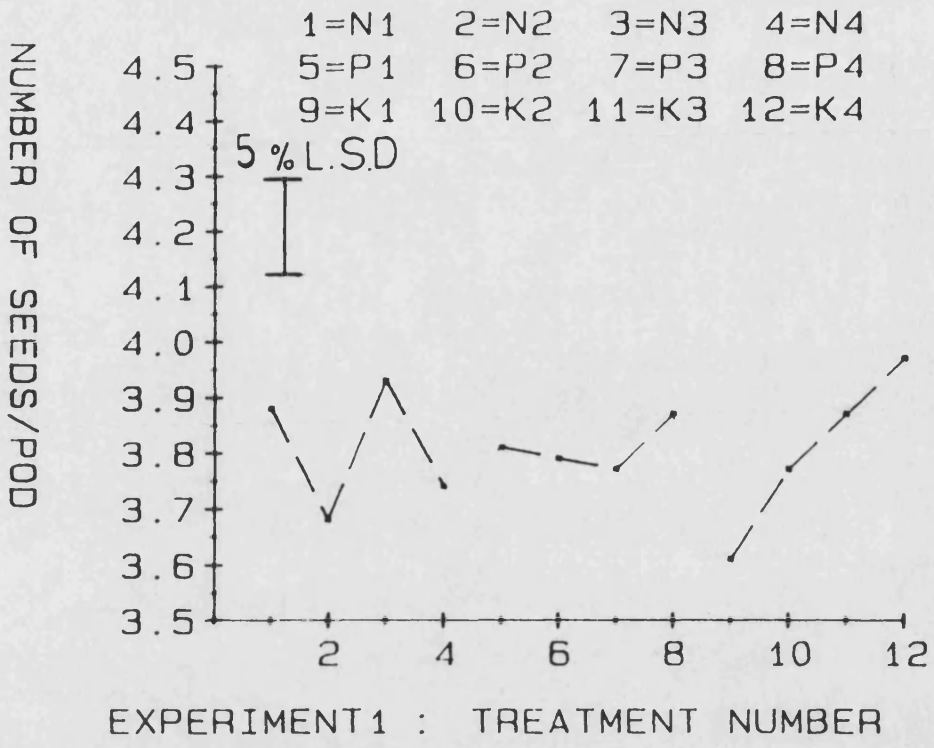

Figure 27. The main effect of N, P and K mineral nutrition levels on the number of seeds produced per pod.

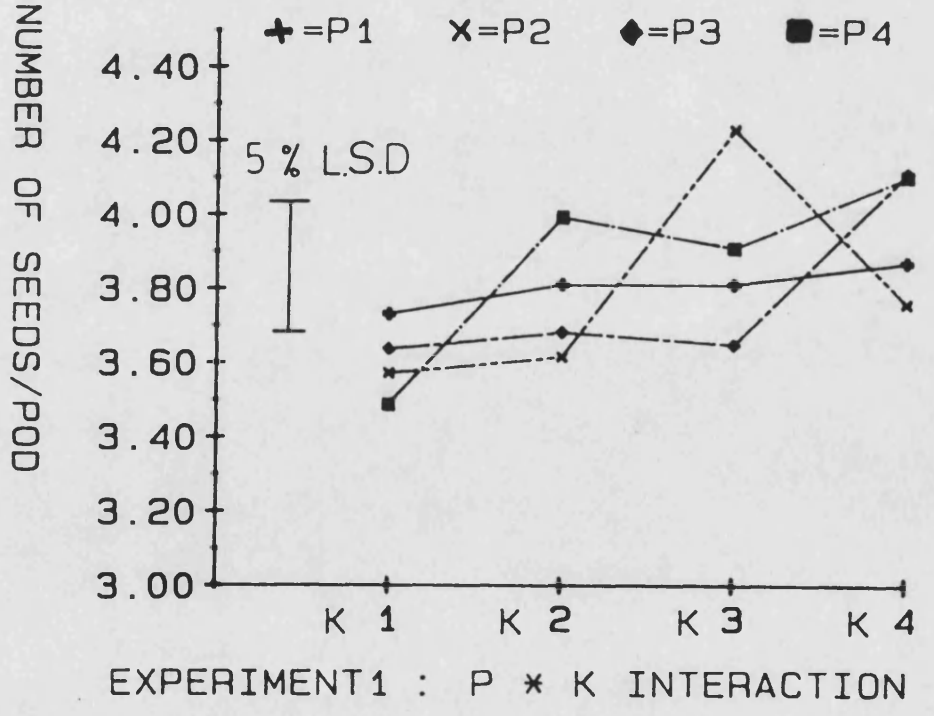

Figure 28. The effect of P and K interaction on the number of seeds per pod.

4.2.2.1 Experiment 2: Number of pods per plant

The number of pods harvested from the plants in each treatment were recorded during harvest in order to examine the effect of N and P nutrition levels on pod number. From the analysis of variance

Total nutrient levels (mg per plant)	Pod number	Total nutrient levels (mg per plant)	Pod number
N_1 = 100	2.47	P_1 = 25	2.41
N_2 = 1000	3.73	P_2 = 250	3.46
		P_3 = 500	3.53
		P_4 = 1000	3.01

Significance levels:

N:	0.1%	P: N.S.	N x P: 1.0%
5% LSD	N: 0.615	P: 0.870	N x P: 1.229

Table 20. The effect of N and P nutrition levels on number of pods per plant in Experiment 2.

presented in Table 20 it can be seen that levels of N and their interaction N and P significantly affected the pod number at 0.1% and 1.0% significance levels respectively.

As shown in Figure 29 the number of pods per plant increased by increasing N levels in the order of $N_1 > N_2$.

Figure 30 shows the effect of N and P interaction on the number of pods produced by each plant. The highest number was achieved by the combination N_2P_4 (4.46) and the lowest by N_1P_4 (1.56).

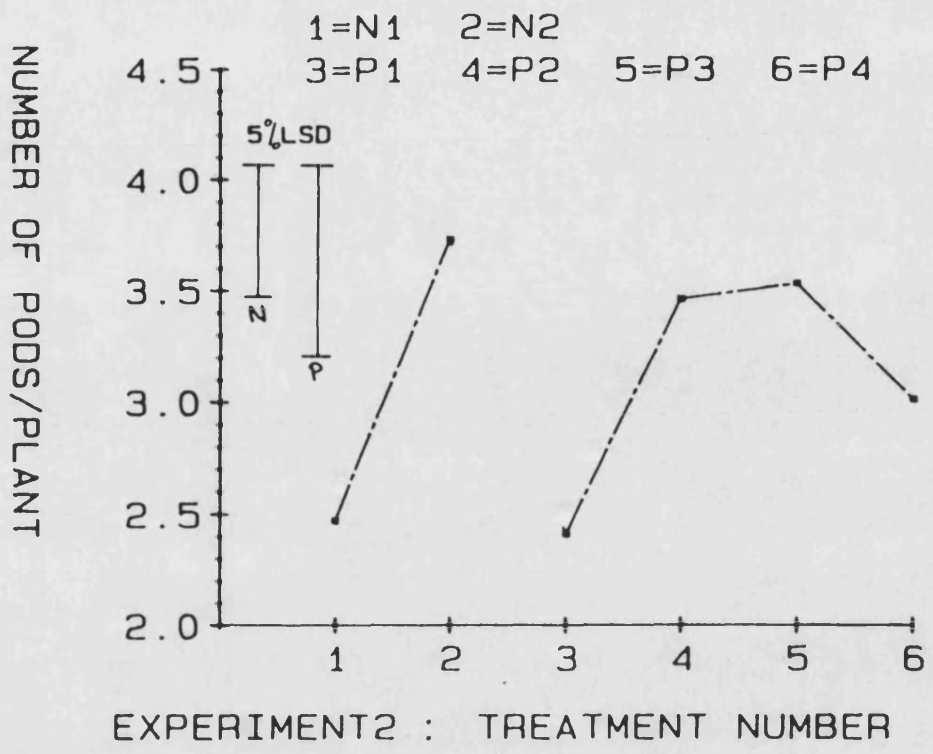

Figure 29. The main effect of N and P mineral nutrition on number of pods produced by a plant.

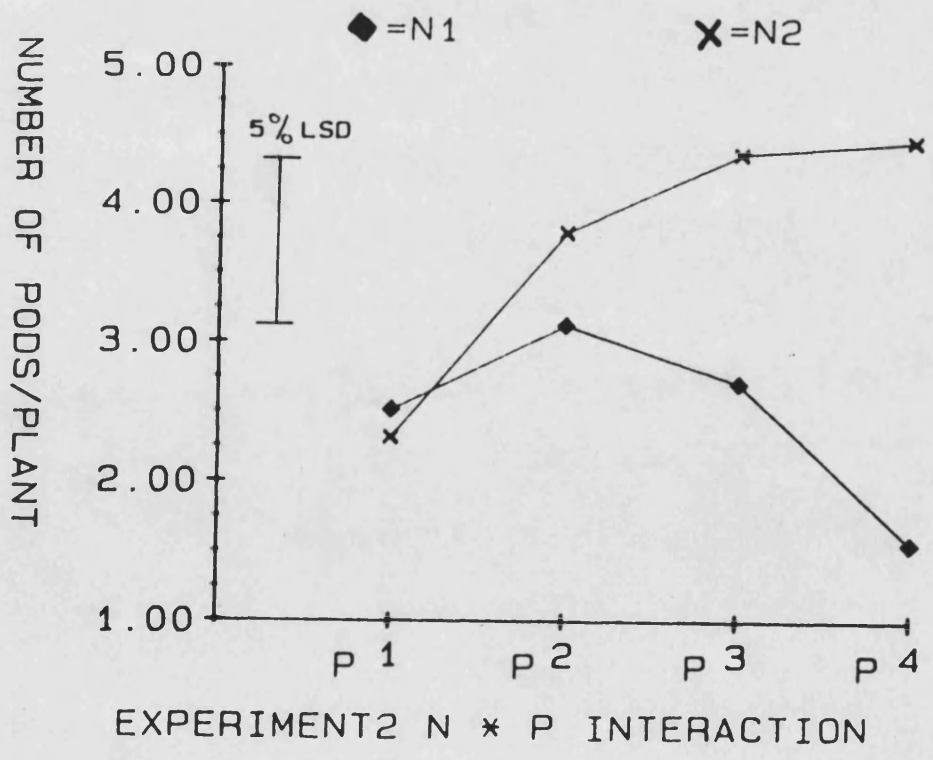

Figure 30. The effect of N and P interaction on the number of pods produced by a plant.

4.2.2.2 Experiment 2: Pod dry weight (g per plant)

The dry weight of the pods from the plants in each treatment were recorded after seed extraction in order to examine the effect of N and P nutrition levels on pod dry matter. From the analysis of

Total nutrient levels (mg per plant)	Pod dry weight (g per plant)	Total nutrient levels (mg per plant)	Pod dry weight (g per plant)
N_1 = 100	0.49	P_1 = 25	0.61
N_2 = 1000	0.81	P_2 = 250	0.69
		P_3 = 500	0.70
		P_4 = 1000	0.61

Significance levels:

N:	0.1%	P: N.S.	N x P: 5.0%
5% LSD	N: 0.101	P: 0.143	N x P: 0.202

Table 21. The effect of N and P nutrition levels on pod dry weight per plant in Experiment 2.

presented in Table 21 it can be seen that levels of N and the N and P interaction significantly affected the pod dry weight at 0.1% and 5.0% significance levels respectively.

As shown in Figure 31, the dry weight of the pods increased significantly with increasing levels of N in the order of $N_1 > N_2$.

Figure 32 shows the effect of N and P interaction on pod dry weight. The highest pod dry weight was achieved by the combination N_2P_4 (2.56 g) and the lowest by N_1P_4 (0.54 g).

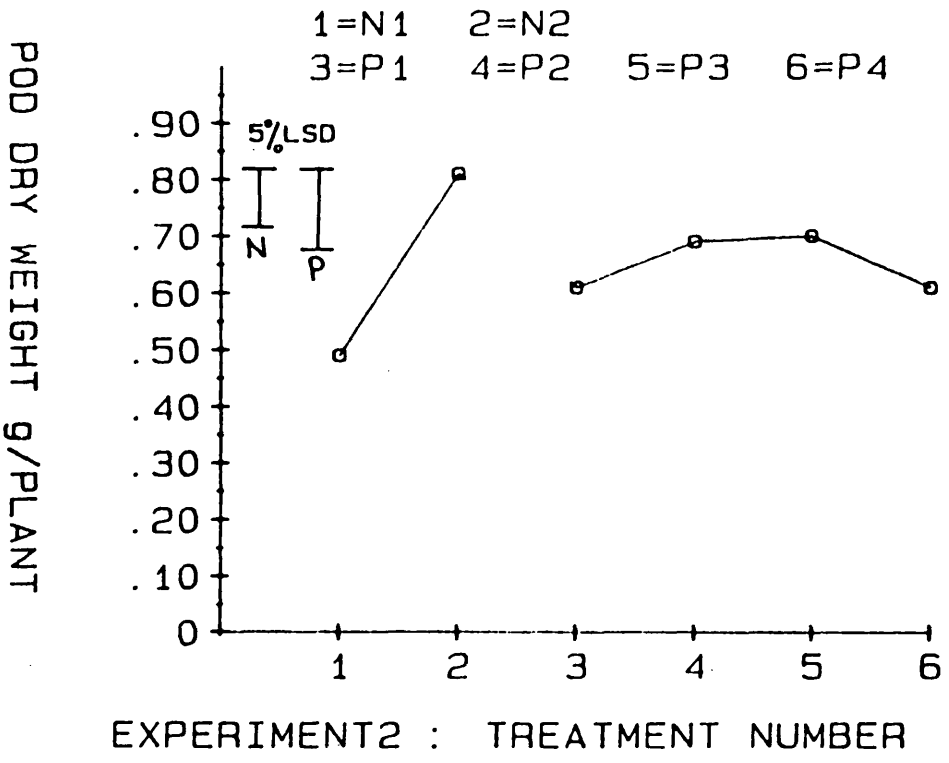

Figure 31. The main effect of N and P mineral nutrition levels on dry weight of pods produced by a plant.

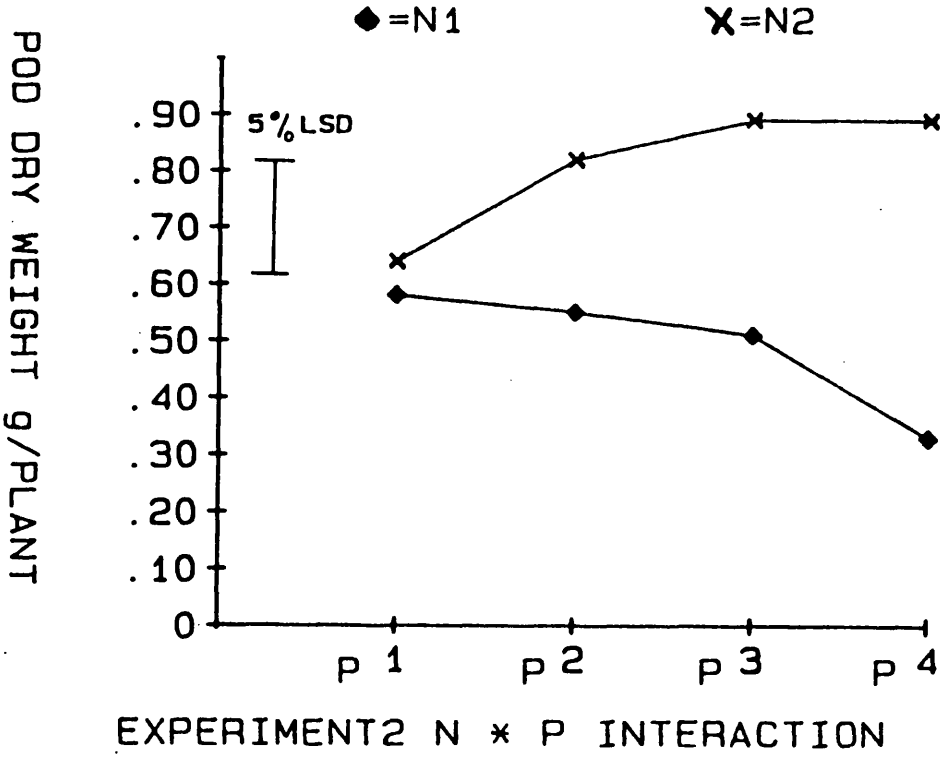

Figure 32. The effect of N and P interaction on the dry weight of empty pods produced by a plant.

4.2.2.3 Experiment 2: Number of Seeds per plant

The number of seeds from plants in each treatment were recorded during pod shelling in order to examine the effect of the N and P nutrition levels on seed yield in terms of number. From the

Total nutrient levels (mg per plant)	Seed number	Total nutrient levels (mg per plant)	Seed number
N_1 = 100	8.30	P_1 = 25	9.02
N_2 = 1000	12.94	P_2 = 250	10.75
		P_3 = 500	12.43
		P_4 = 1000	10.28

Significance levels:

N:	0.1%	P: N.S.	N x P: 0.1%
5% LSD	N: 2.03	P: 2.87	N x P: 4.05

Table 22. The effect of N and P nutrition levels on the number of seeds per plant in Experiment 2.

analysis of variance presented in Table 22 it can be seen that levels of N and the N and P interaction significantly affected the seed number both at 0.1% significance level in this experiment.

As shown in Figure 33, the number of seeds per plant increased with increasing levels of N in the order of $N_1 > N_2$.

Figure 34 shows the effect of N and P interaction on the number of seeds per plant. The highest seed number was achieved by the combination N_2P_4 (16.62) and the lowest by N_1P_4 (3.93).

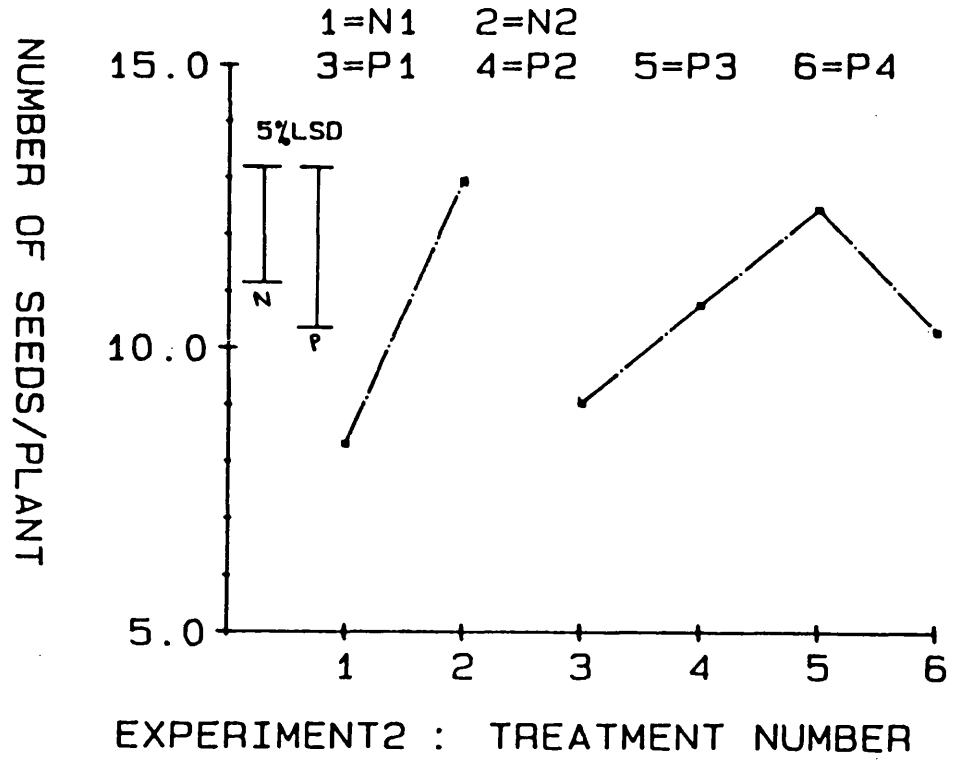

Figure 33. The main effect of N and P mineral nutrition levels on the number of seeds produced by a plant.

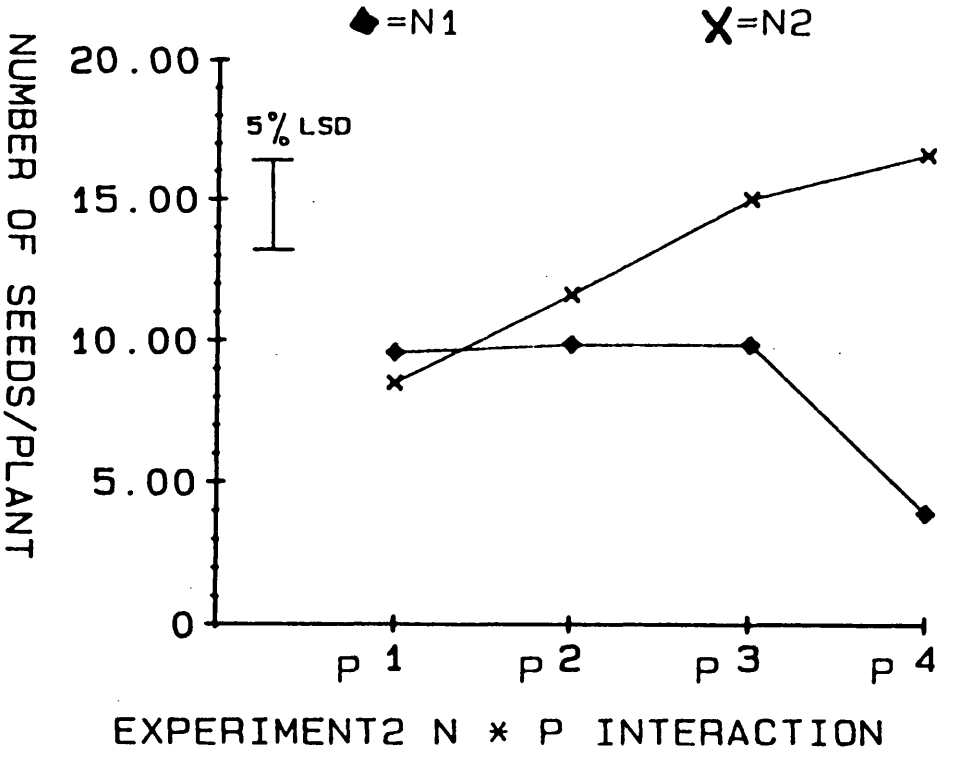

Figure 34. The effect of N and P interaction on the number of seeds produced by a plant.

4.2.2.4 Experiment 2: Seed dry weight (g per plant)

The weight of the seeds from the plants in each treatment were recorded when the seed moisture content was at 11 ± 0.5% in order to examine the effect of the N and P nutrition levels on seed yield.

Total nutrient levels (mg per plant)	Seed dry weight (g per plant)	Total nutrient levels (mg per plant)	Seed dry weight (g per plant)
N_1 = 100	1.18	P_1 = 25	1.25
N_2 = 1000	2.18	P_2 = 250	1.86
		P_3 = 500	2.08
		P_4 = 1000	1.55

Significance levels:

N:	0.1%	P: 5.0%	N x P: 1.0%
5% LSD	N: 0.408	P: 0.577	N x P: 0.816

Table 23. The effect of N and P nutrition levels on the seed dry weight per plant in Experiment 2.

From the analysis of variance presented in Table 23, it can be seen that levels of N, P and their interaction (NP) significantly affected the dry weight of seeds per plant at 0.1%, 5.0% and 1.0% significance levels in this experiment.

As shown in Figure 35, seed dry weight increased with increasing levels of N, and levels of P had also similar effect up to P_3 and declined from P_3 to P_4, in the order of $N_2 > N_1$ and $P_1 < P_4 < P_2 < P_3$.

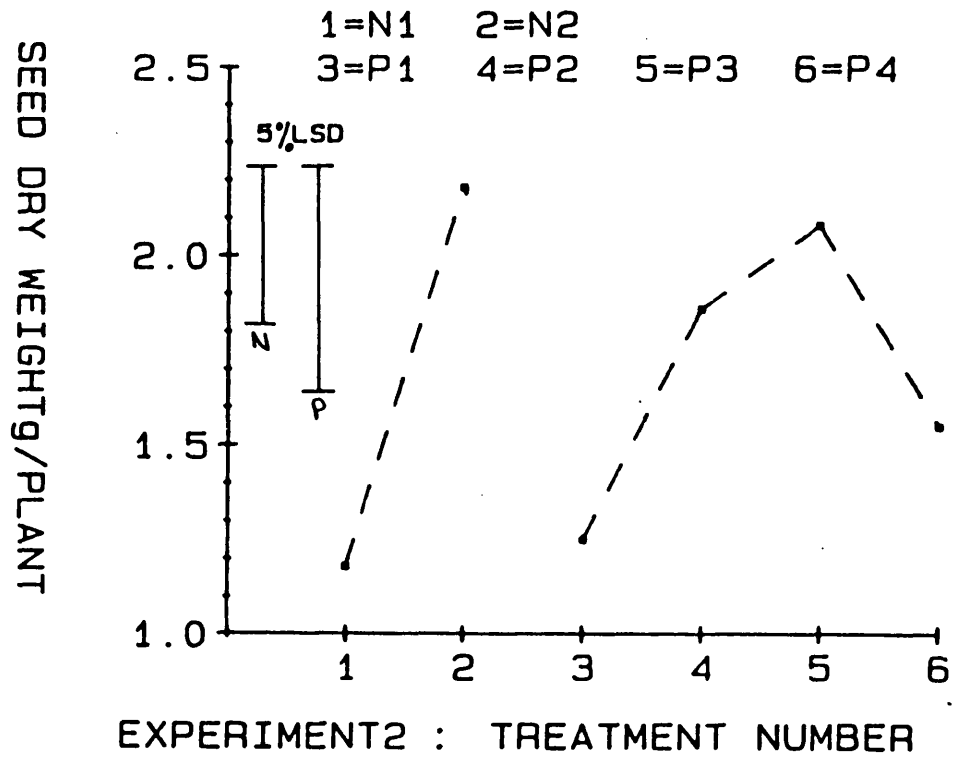

Figure 35. The main effect of N and P mineral nutrition levels on the seed yield as determined by seed dry weight per plant.

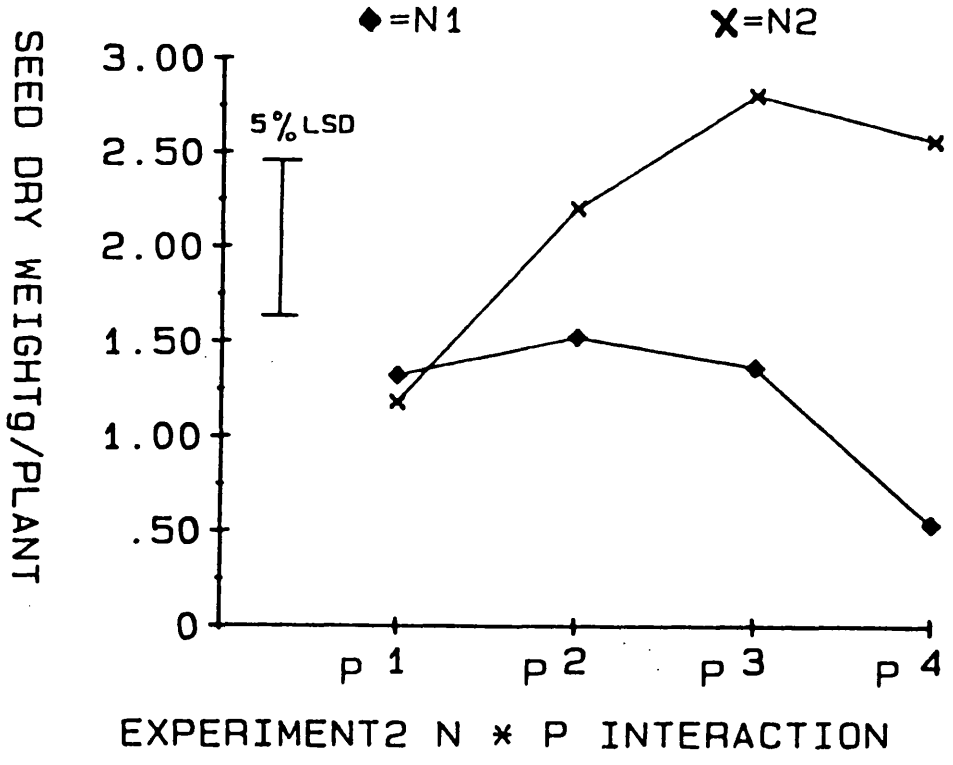

Figure 36. The effect of N and P interaction on the seed yield as determined by seed dry weight per plant.

Figure 36 shows the effect of N and P interaction on seed dry weight produced per plant. The highest dry weight was achieved by the combination N_2P_4 (2.56 g) and the lowest by N_1P_4 (0.54 g).

4.2.2.5 Experiment 2: Number of seeds per pod

The number of seeds per pod was calculated by dividing total seed number by total pod number in each treatment in order to examine the effect of N and P nutrition levels on seed set per pod. From the analysis of variance presented in Table 24, it can be seen that only levels of P and the N x P interaction significantly affected the seed number per pod at only 5.0% significance level in this experiment.

Total nutrient levels (mg per plant)	Number of seeds per pod	Total nutrient levels (mg per plant)	Number of seeds per pod
N_1 = 100	3.311	P_1 = 25	3.782
N_2 = 1000	3.494	P_2 = 250	3.143
		P_3 = 500	3.541
		P_4 = 1000	3.143

Significance levels:

N:	N.S.	P: 5.0%	N x P: 5.0%
5% LSD	N: 0.37	P: 0.53	N x P: 0.74

Table 24. The effect of N and P nutrition levels on number of seeds per pod in Experiment 2.

As shown in Figure 37, the number of seeds per pod increased

with increasing N levels but not significantly and that the effect of p levels were in the order of $P_1 > P_3 > P_2 = P_4$.

Figure 38 shows the effect of N and P interaction on the number of seeds per pod. The highest number of seeds per pod was achieved by the combination N_2P_4 (3.76) and the lowest by N_1P_4 (2.52).

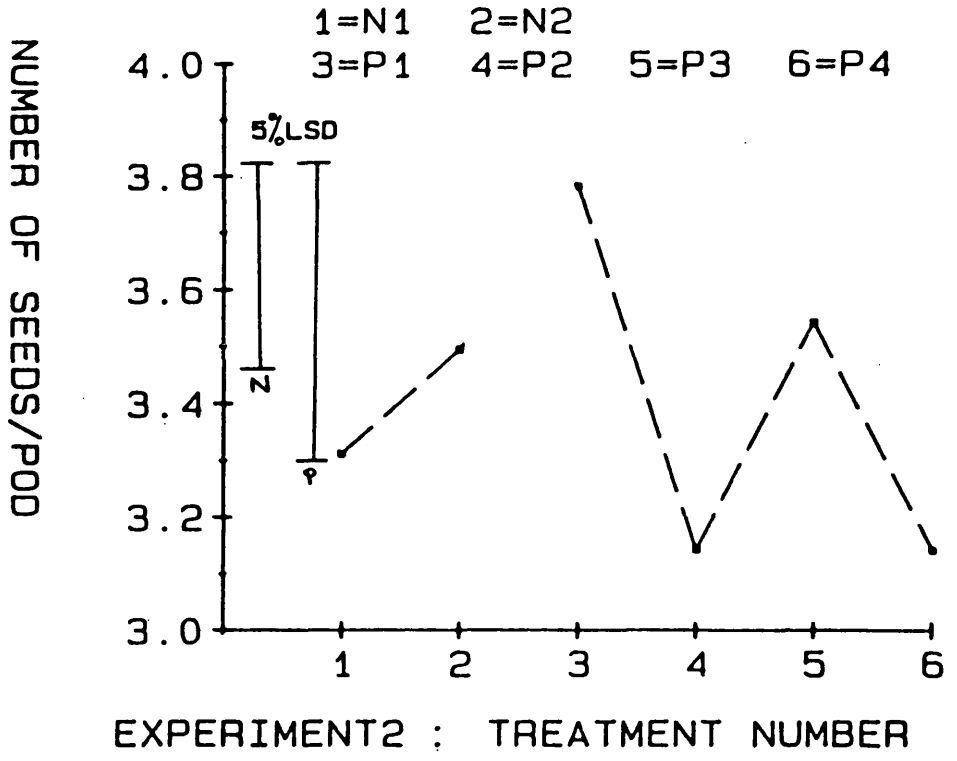

Figure 37. The main effect of N and P mineral nutrition levels on the number of seeds per pod produced by a plant.

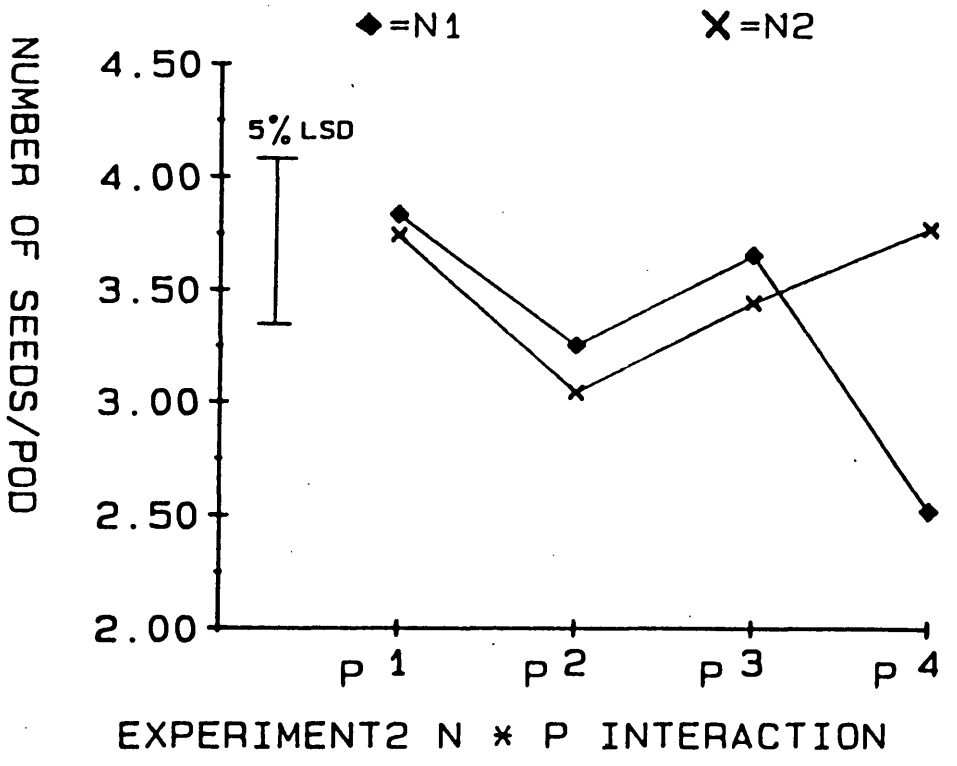

Figure 38. The effect of N and P interaction on the number of seeds per pod produced by a plant.

4.2.3.3 Experiment 3: Number of seeds per plant

The number of seeds from each treatment were recorded during pod shelling in order to examine the effect of N, P and K nutrition levels on number of seeds produced per plant. From the analysis of

Total nutrient levels (kg per ha)	Number of seeds per plant	Total nutrient levels (kg per ha)	Number of seeds per plant	Total nutrient levels (kg per ha)	Number of seeds per plant
N_1 = 0	26.63	P_1 = 0	29.11	K_1 = 0	28.15
N_2 = 25	29 .75	P_2 = 50	28.21	K_2 = 25	28.71
N_3 = 75	29.39	P_3 = 150	28.45	K_3 = 75	28.91

Significance levels:

N: N.S. N x P: N.S.

P: N.S. N x K: N.S. N x P x K: NS

K: N.S. P x K: N.S.

L.S.D. 5%
(N,P,K) = 3.17 (NxP,PxK,NxK) = 5.48 (N x P x K) = 9.50

Table 25. The effect of N, P and K nutrition levels on the number of seeds per plant in Experiment 3.

variance presented in Table 25, it can be seen that N, P, K and their interaction levels had no significant effect on seed number per plant.

Figure 39 shows the main effect of N, P and K on seed number per plant in this experiment.

Figure 40 shows the effect of N and P interaction on the seed number.

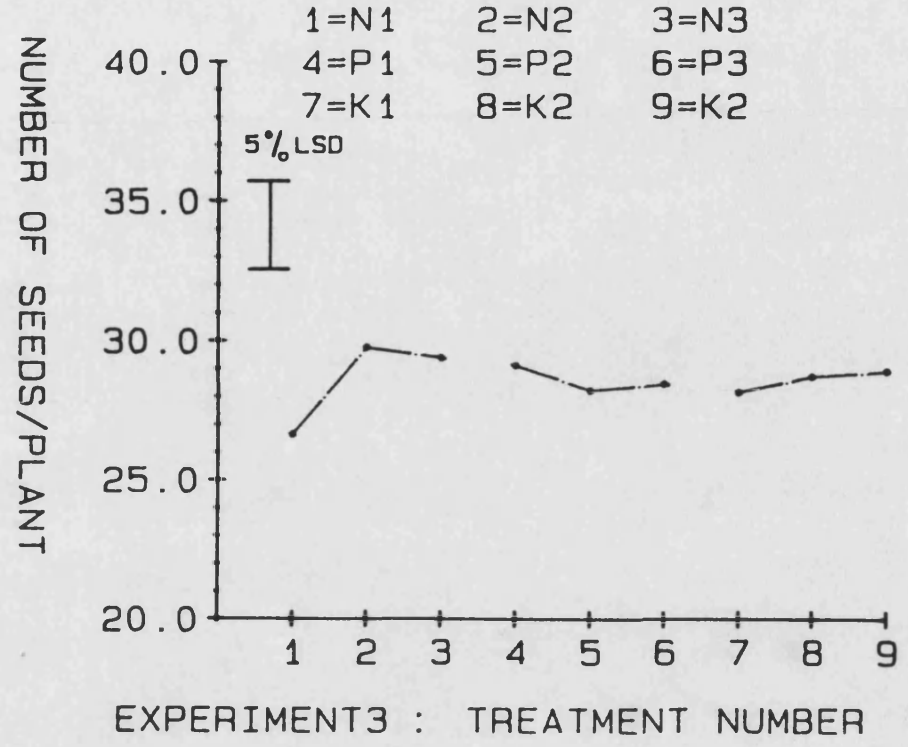

Figure 39. The main effect of N, P and K mineral nutrition levels on seed yield as determined by seed number per plant.

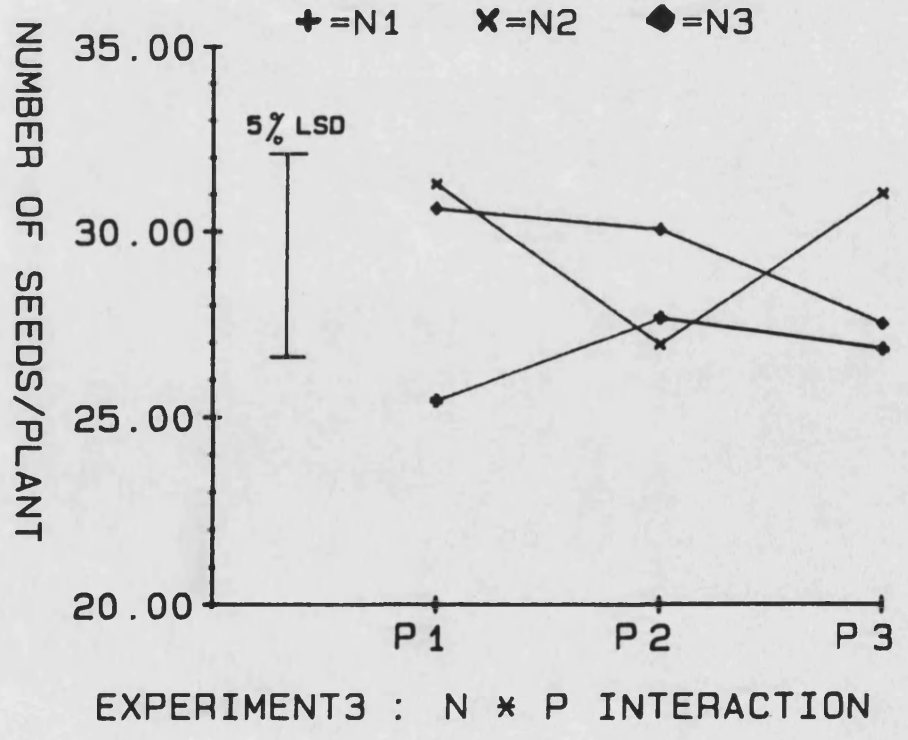

Figure 40. The effectof N and P interaction on the number of seeds produced per plant.

4.2.3.4 Experiment 3: Seed dry weight (g per plant)

The weight of the seeds from the plants in each treatment were recorded when the seeds' moisture content were at 11 ± 0.5% in order to examine the effect of the N, P and K mineral nutrition levels on seed yield. From the analysis of variance presented in Table 26, it

Total nutrient levels (kg per ha)	Seed dry weight (g per plant)	Total nutrient levels (kg per ha)	Seed dry weight (g per plant)	Total nutrient levels (kg per ha)	Seed dry weight (g per plant)
N_1 = 0	4.94	P_1 = 0	5.42	K_1 = 0	5.28
N_2 = 25	5.47	P_2 = 50	5.38	K_2 = 25	5.28
N_3 = 75	5.61	P_3 = 150	5.23	K_3 = 75	5.46

Significance levels:

N: N.S. N x P: N.S.

P: N.S. N x K: N.S. N x P x K: N.S.

K: N.S. P x K: N.S.

L.S.D. 5%
(N,P,K) = 0.71 (NxP,PxK,NxK) = 1.22 (N x P x K) = 2.11

Table 26. The effect of N, P and K nutrition levels on seed dry weight in g per plant in Experiment 3.

can be seen that N, P, K and their interaction levels had no significant effect on seed dry weight.

Figure 41 shows the main effect of N, P and K on seed dry weight per plant in this experiment.

Figure 42 shows the effect of N P interaction on seed dry weight.

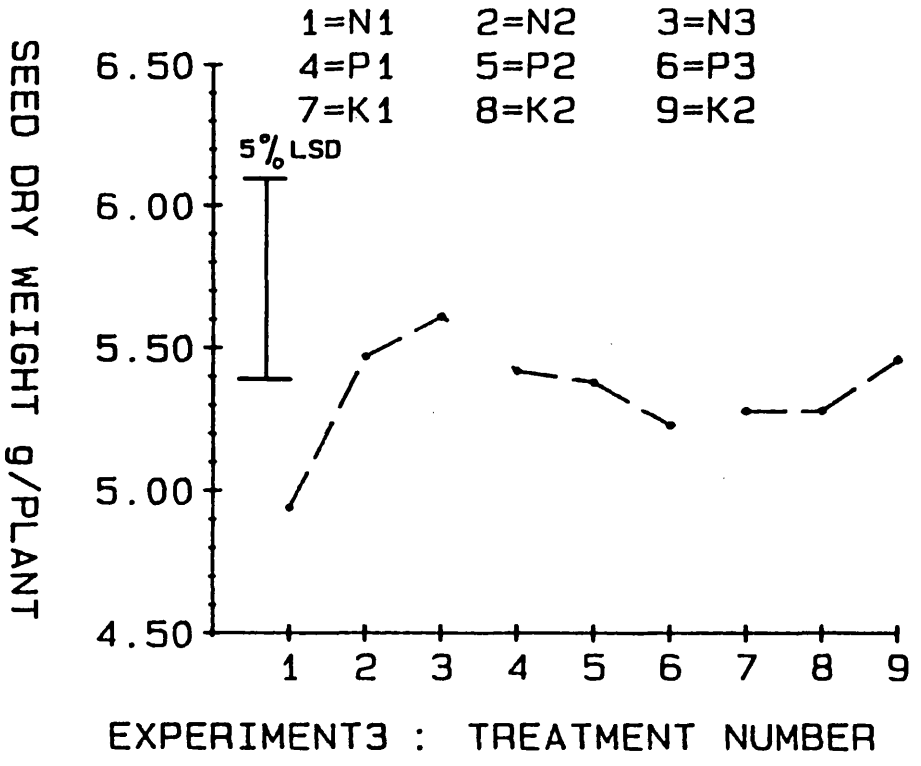

Figure 41. The main effect of N, P and K mineral nutrition levels on seed yield as determined by seed dry weight per plant.

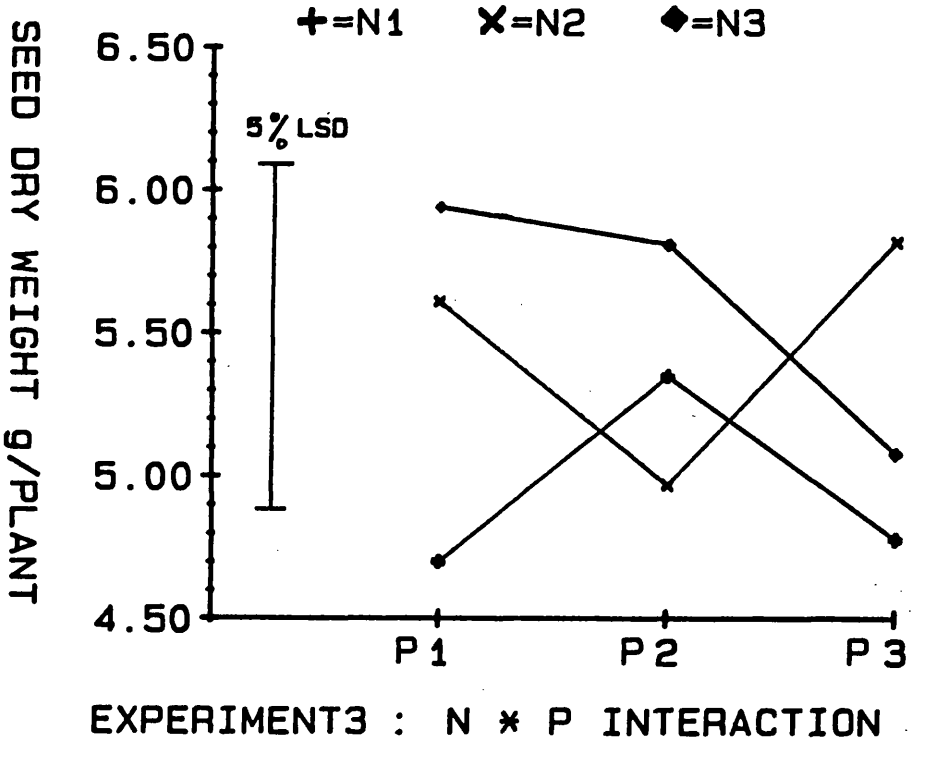

Figure 42. The effect of N and P interaction on seed dry weight per plant.

4.2.4.1 Experiment 4: Number of pods per plant

The number of pods from the 36 plants in each treatment were recorded during harvest in order to examine the effect of the N and K nutrition levels on pod number. From the analysis of variance

Total nutrient levels (mg per plant)	Number of pods per plant	Total nutrient levels (mg per plant)	Number of pods per plant
N_1 = 0	5.18	K_1 = 0	5.81
N_2 = 100	4.77	K_2 = 50	5.88
N_3 = 500	6.41	K_3 = 250	6.06
N_4 = 1000	7.03	K_4 = 500	5.65

Significance levels:

N: 0.1% P: N.S., and their interaction: N.S.

5% LSD = 0.83

Table 27. The effectof N and K nutrition levels on number of pods per plant in Experiment 4.

presented in Table 27, it can be seen that only the levels of N nutrition affected pod number significantly at 0.1% level. Neither K nor their interaction N x K had a significant effect.

As shown in Figure 43, pod number increased with increasing levels of N after a slight initial decrease from N_1 to N_2 in this experiment in the order of $N_2 < N_1 < N_3 < N_4$.

Figure 44 shows the effect of N and K interaction on the number of pods produced by a plant. The highest pod number was achieved by the combination N_4K_1 (7.70) and the lowest by N_2K_3 (3.79).

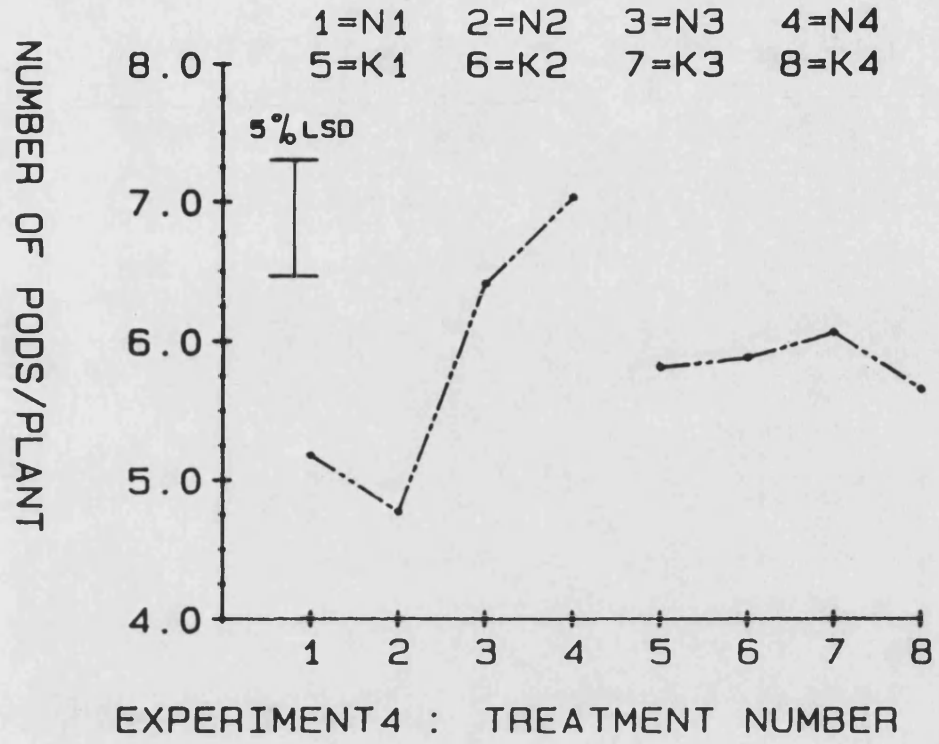

Figure 43. The main effect of N and K mineral nutrition levels on the number of pods produced per plant

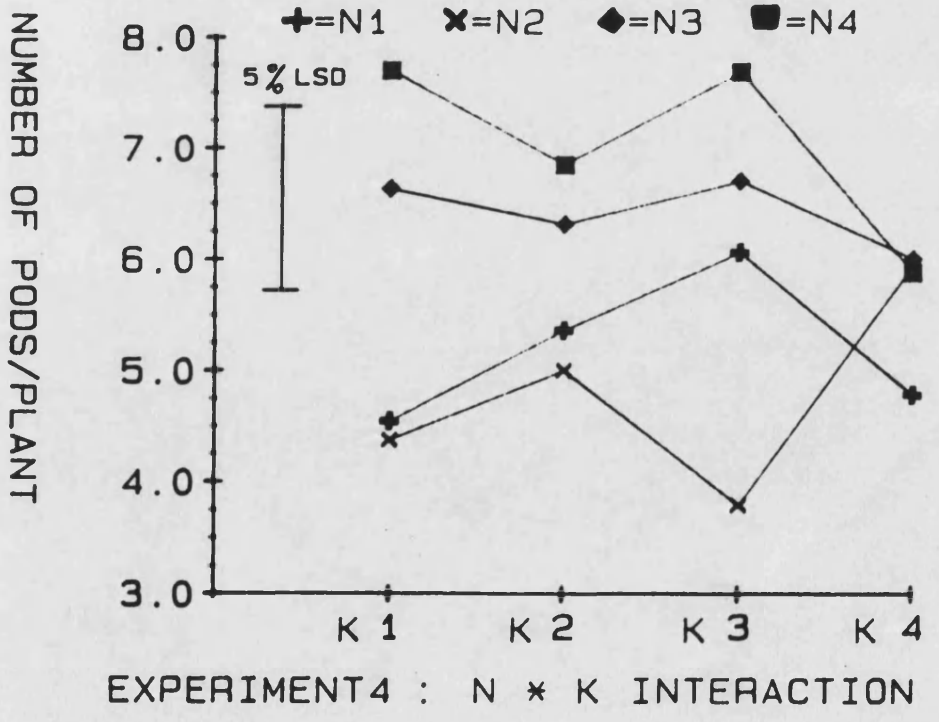

Figure 44. The effect of N and K interaction on the number of pods produced per plant.

4.2.4.2 Experiment 4: Pod dry weight per plant

The dry weight of the pods from the 36 plants in each treatment were recorded after seed extraction in order to examine the effect of the N and K nutrient levels on pod dry weighit. From the

Total nutrient levels (mg per plant)	Pod dry weight (g per plant)	Total nutrient levels (mg per plant)	Pod dry weight (g per plant)
N_1 = 0	1.12	K_1 = 0	1.14
N_2 = 100	1.06	K_2 = 50	1.24
N_3 = 500	1.30	K_3 = 250	1.27
N_4 = 1000	1.44	K_4 = 500	1.27

Significance levels:

N: 0.1% K: N.S., and their interaction: N.S.

5% LSD = 0.165

Table 28. The effect of N and K nutrition levels on pod dry weight per plant in Experiment 4.

analysis of variance presented in Table 28 it can be seen that only levels of N nutrition affected the pod dry weight significantly at 0.1% level. Neither K nor their interaction N x K had a significant effect.

As shown in Figure 45, pod dry weight increased with increasing levels of N in this experiment in the order of $N_2 < N_1 < N_3 < N_4$.

Figure 46 shows the effect of N x K interaction in pod dry weight.

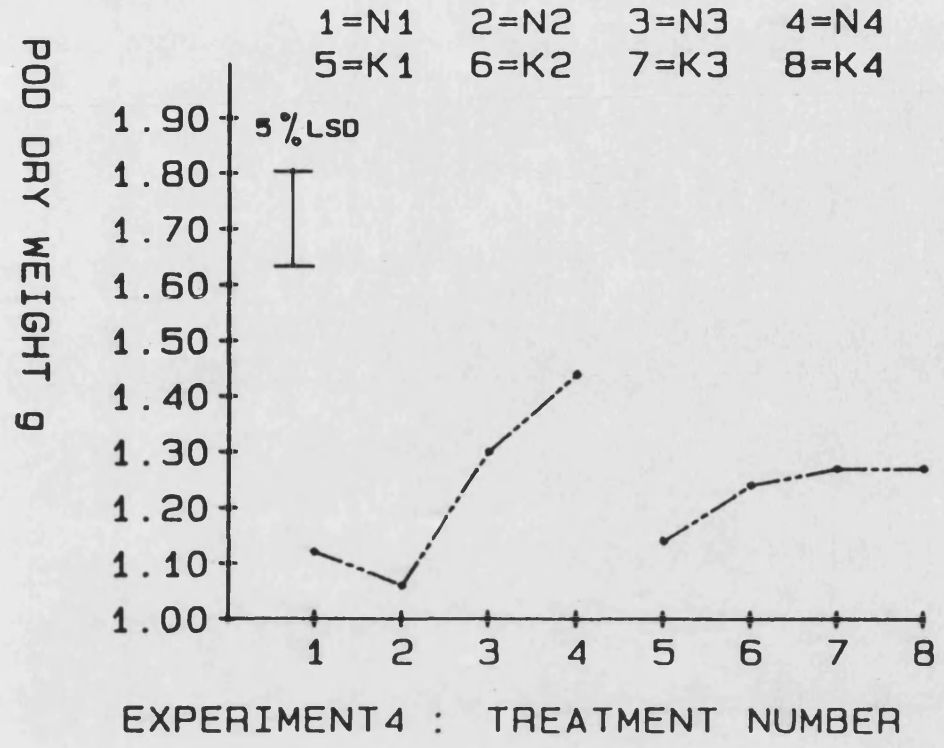

Figure 45. The main effect of N and K mineral nutrition levels on the empty dry weight of pods produced per plant.

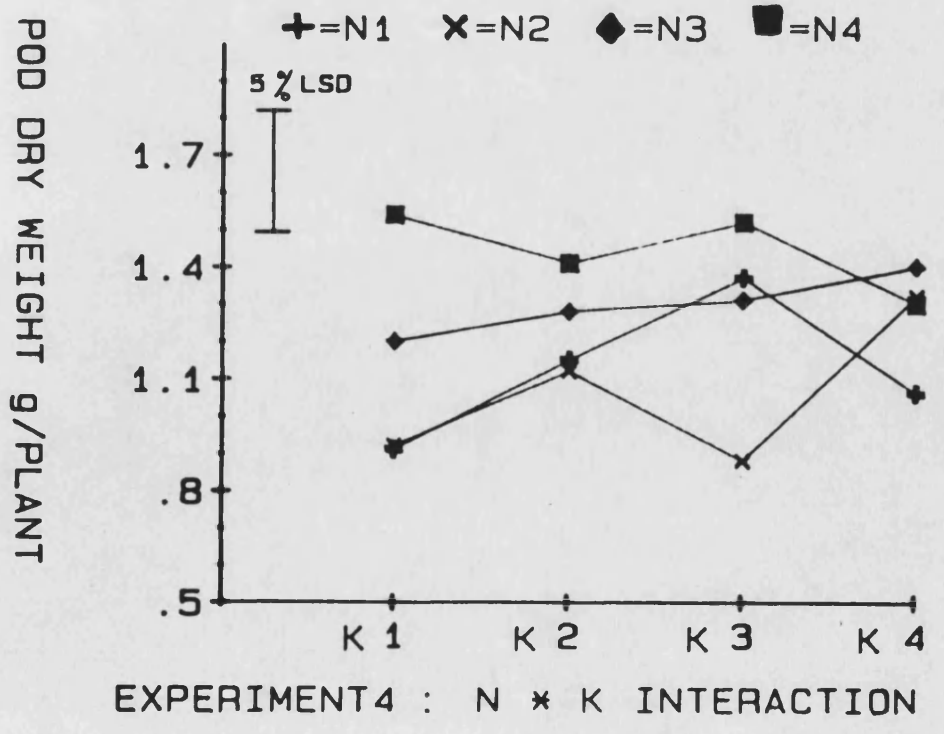

Figure 46. The effect of N and K interaction on pod dry weight per plant.

4.2.4.3 Experiment 4: Number of seeds per plant

The number of seeds from the 36 plants in each treatment were recorded during pod shelling in order to examine the effect of the N and K nutrition levels on seed yield in terms of number. From

Total nutrient levels (mg per plant)	Number of seeds per plant	Total nutrient levels (mg per plant)	Number of seeds per plant
$N_1 = 0$	23.08	$K_1 = 0$	20.56
$N_2 = 100$	21.81	$K_2 = 50$	26.00
$N_3 = 500$	26.36	$K_3 = 250$	27.14
$N_4 = 1000$	28.92	$K_4 = 500$	26.47

Significance levels:

N: 0.1% K: 1.0%S, and their interaction: 5.0%

5% LSD = 3.42

Table 29. The effect of N and K nutrition levels on the number of seeds per plant in Experiment 4.

the analysis of variance presented in Tale 29, it can be seen that N, K and their interaction N x K affected the seed number significantly at 0.1%, 1.0% and 5.0% levels respectively.

As shown in Figure 47, seed number increased with increasing levels of N after a slight initial decrease from N_1 to N_2 in the order of $N_2 < N_1 < N_3 < N_4$ and that increasing levels of K also increased the seed number up to K_3 and declined at K_4, in the order of $K_1 < K_2 < K_3 > K_4$.

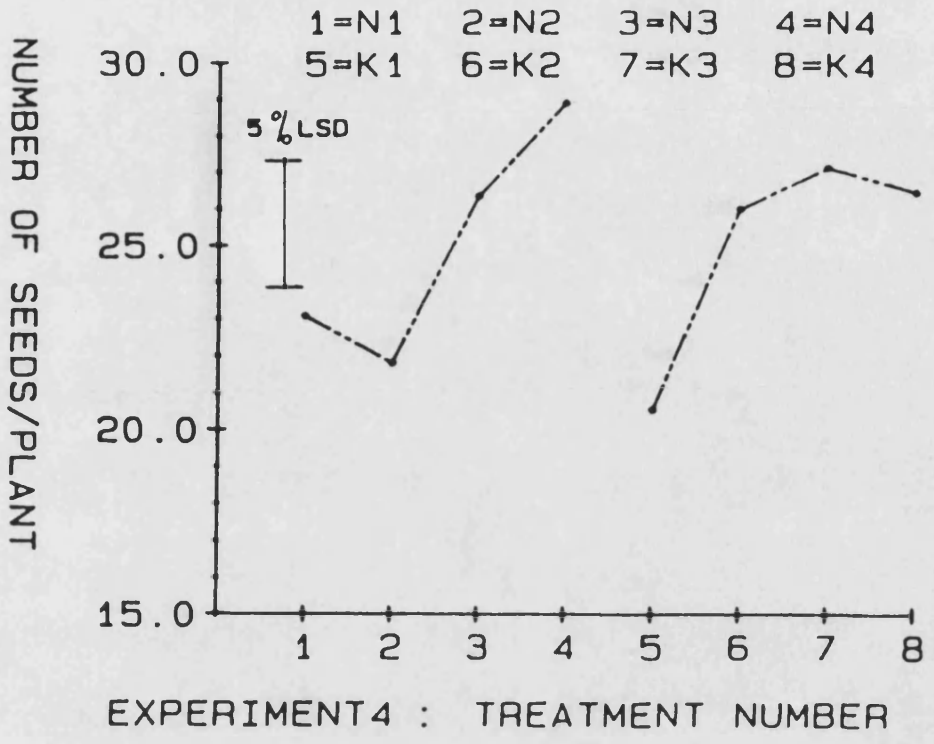

Figure 47. The main effect of N and K mineral nutrition levels on the number of seeds per plant.

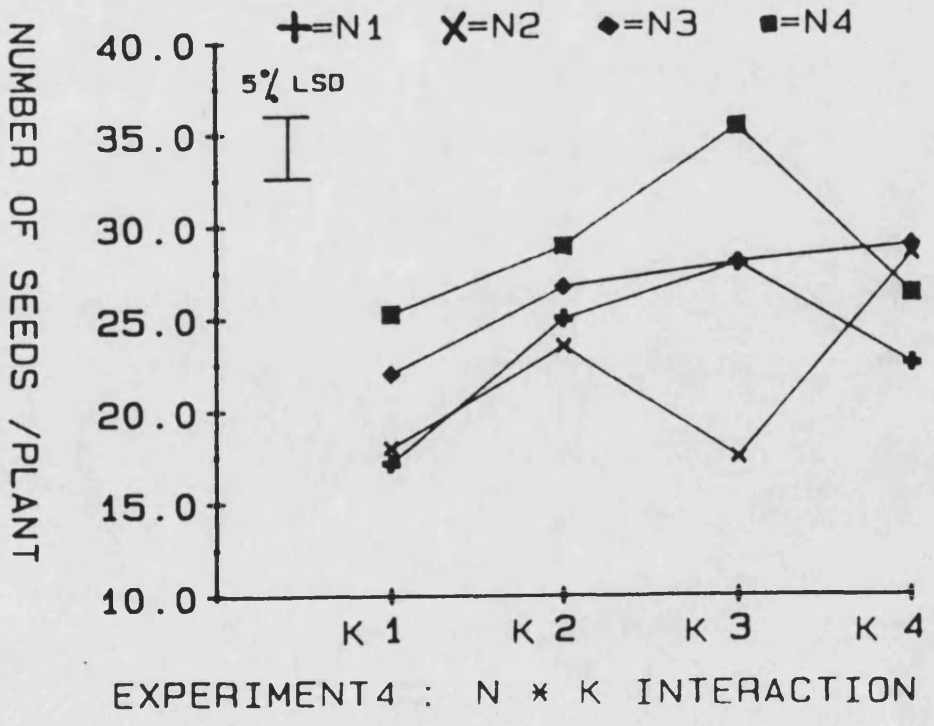

Figure 48. The effect of N and K interaction on the number of seeds per plant.

Figure 48 shows the effect of N and K interaction on seed number. The highest seed number per plant was achieved by the combination N_4K_3 (35.34) and the lowest by N_1K_1 (17.10).

4.2.4.4 Experiment 4: Seed dry weight (g per plant)

The weight of the seeds from the 36 plants in each treatment were recorded when the seed moisture content was at 11 ± 0.5%, in order to examine the effect of the N and K nutrition levels on seed yield per plant. From the analysis of variance presented in Table 30

Total nutrient levels (mg per plant)	Seed dry weight (g per plant)	Total nutrient levels (mg per plant)	Seed dry weight (g per plant)
N_1 = 0	4.86	K_1 = 0	3.68
N_2 = 100	4.58	K_2 = 50	5.18
N_3 = 500	5.60	K_3 = 250	6.14
N_4 = 1000	6.13	K_4 = 500	6.17

Significance levels:

N: 1.0% K: 0.1%; and their interaction: 5%.

5% LSD = 0.79

Table 30. The effect of N and K nutrition levels on seed dry weight (g per plant) in Experiment 4.

it can be seen that N, K and their interaction N x K affected the seed dry weight significantly at 1.0%, 0.1% and 5% levels respectively.

As shown in Figure 49, seed dry weight increased with increasing levels of N after a slight initial decrease from N_1 to N_2 in the order of $N_2 < N_1 < N_3 < N_4$, and that increasing levels of K also increased seed yield in the order of $K_1 < K_2 < K_3 < K_4$.

Figure 50 shows the effect of N and K interaction on seed yield. The highest seed dry weight was achieved by the combination N_4K_3 (8.08 g) and the lowest by N_1K_1 (3.16 g).

4.2.4.5 Experiment 4: Number of seeds per pod

The number of seeds per pod were calculated by dividing total seed number by total pod number in each treatment in order to examine the effect of N and K nutrition levels on seed set per pod. From the

Total nutrient levels (mg per plant)	Number of seeds per pod	Total nutrient levels (mg per plant)	Number of seeds per pod
$N_1 = 0$	4.42	$K_1 = 0$	3.64
$N_2 = 100$	4.56	$K_2 = 50$	4.44
$N_3 = 500$	4.15	$K_3 = 250$	4.51
$N_4 = 1000$	4.16	$K_4 = 500$	4.69

Significance levels:

N: 1.0% K: 0.1%, and their interaction: N.S.

5% LSD = 0.263

Table 31. The effect of N and K nutrition levels on number of seeds per pod in Experiment 4.

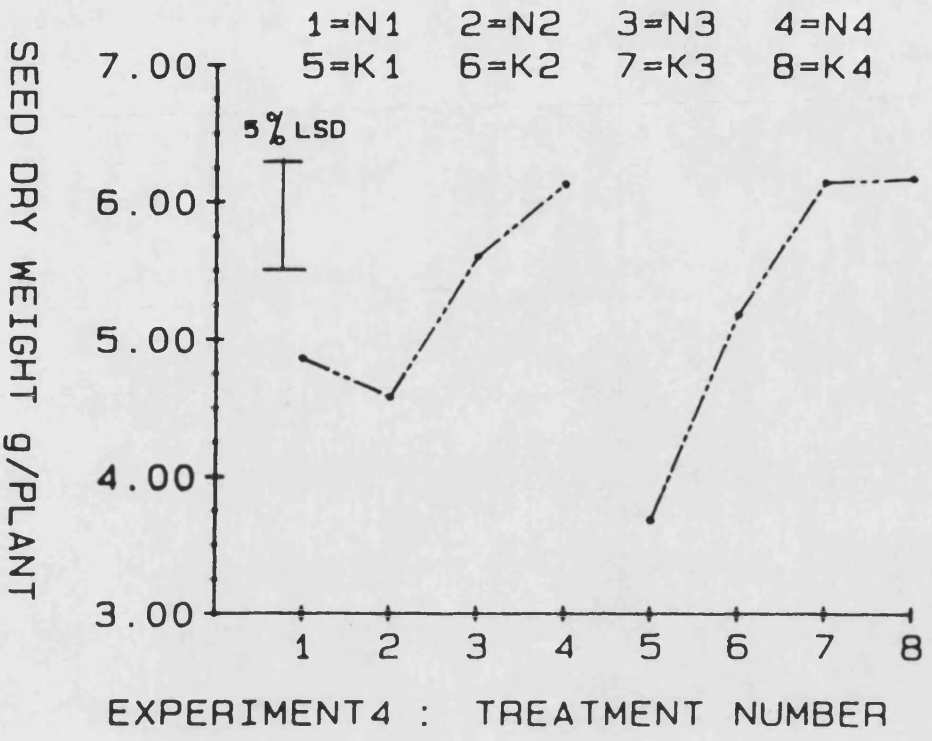

Figure 49. The main effect of N and K mineral nutrition levels on seed dry weight per plant.

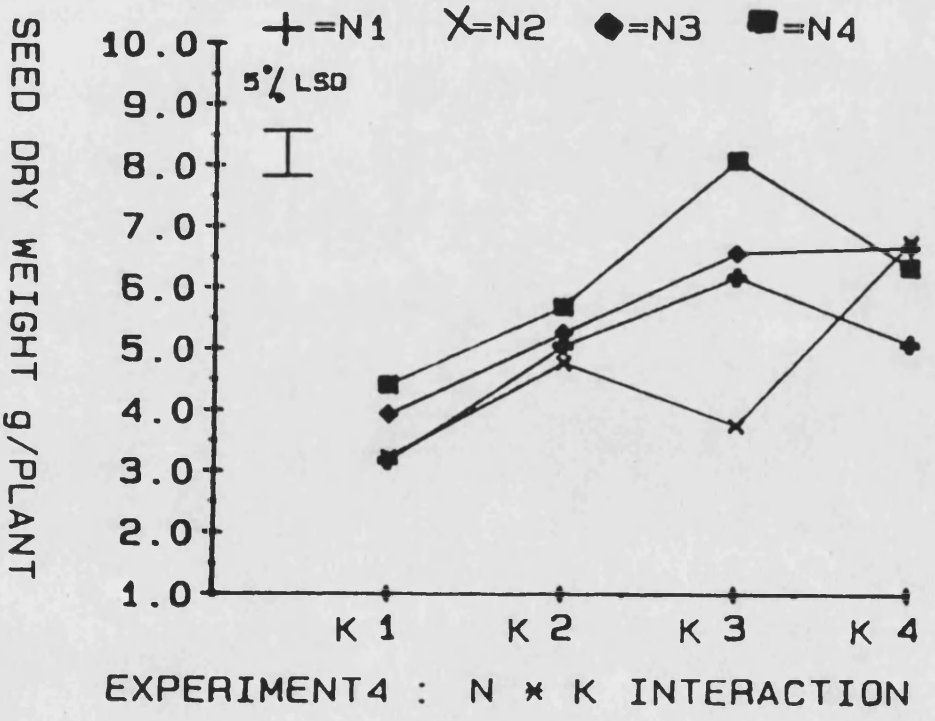

Figure 50. The effect of the interaction of the N and K mineral nutrition levels on seed dry weight per plant.

analysis of variance presented in Table 31 it can be seen that N and K affected the number of seeds per pod significantly at 1.0% and 0.1% levels. The N and K interaction had no significant effect.

As shown in Figure 51 the number of seeds per pod decreased, after a slight initial increase, with increasing levels of N in the order of $N_1 < N_2 > N_3 > N_4$; and increasing levels of K increased the number of seeds per pod in this experiment in the order of $K_1 < K_2 < K_3 < K_4$.

Figure 52 shows the effect of N x K interaction on the number of seeds produced per pod.

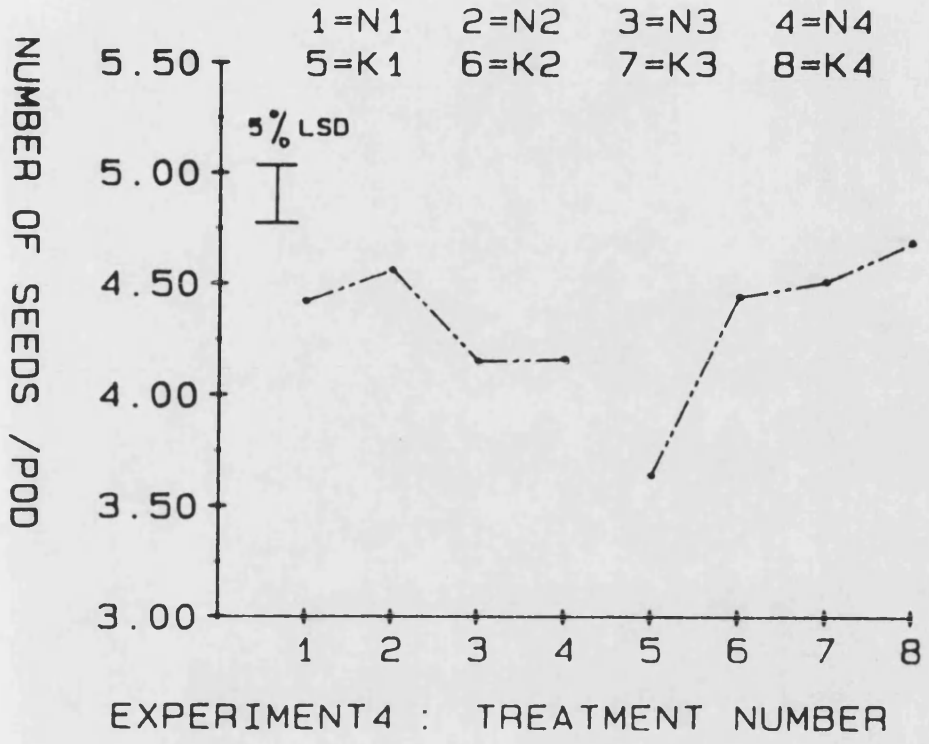

Figure 51. The main effect of N and K mineral nutrition levels on the number of seeds produced per pod.

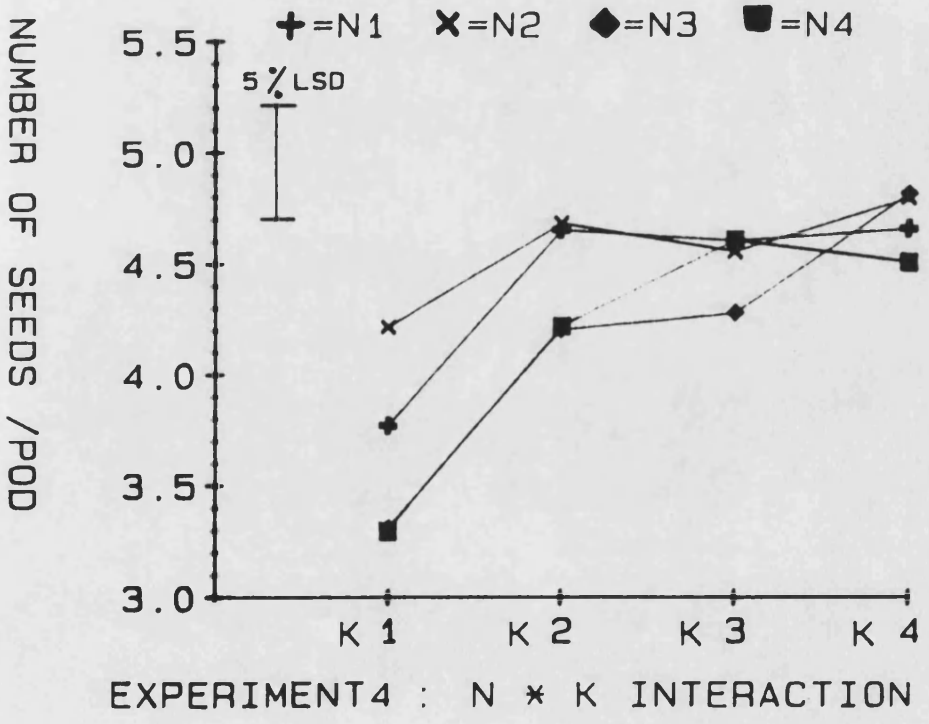

Figure 52. The effect of N K interaction on the number of seeds produced per pod.

4.3 Seed Chemical Composition

4.3.1.1 Experiment 1: Total seed nitrogen content

The total seed nitrogen content was determined in seed samples (Section 3.2.1) from each treatment in order to examine the effect of N, P and K mineral nutrition levels on seed N content and to attempt to establish a relationship between seed yield and quality. From the analysis of variance presented in Table 33, it can be seen that the levels of N, P and K and their interactions NP, NK, PK and NPK significantly affected seeds' total N content at 0.1% significance level except for P which is at the 1.0% significance level.

Total nutrient levels (mg per plant)	N (mg per g)	Total Nutrient levels (mg per plant)	P (mg per g)	Total nutrient levels (mg per plant)	N (mg per g)
N_1 = 100	43.49	P_1 = 50	48.46	K_1 = 40	49.23
N_2 = 150	45.65	P_2 = 70	48.41	K_2 = 60	48.72
N_3 = 300	50.05	P_3 = 140	48.05	K_3 = 120	46.25
N_4 = 500	51.89	P_4 =210	46.17	K_4 = 180	46.89

Significance levels:

N: 0.1% N x P: 0.1%

P: 1.0% N x K: 0.1% N x P x K: 0.1%

K: 0.1% P x K: 0.1%

L.S.D. (N,P,K) = 1.47 (NxP,PxK,NxK) = 2.94 (N x P x K) = 5.89

Table 33. The effect of N, P and K mineral nutrition levels on total seed nitrogen content in Experiment 1.

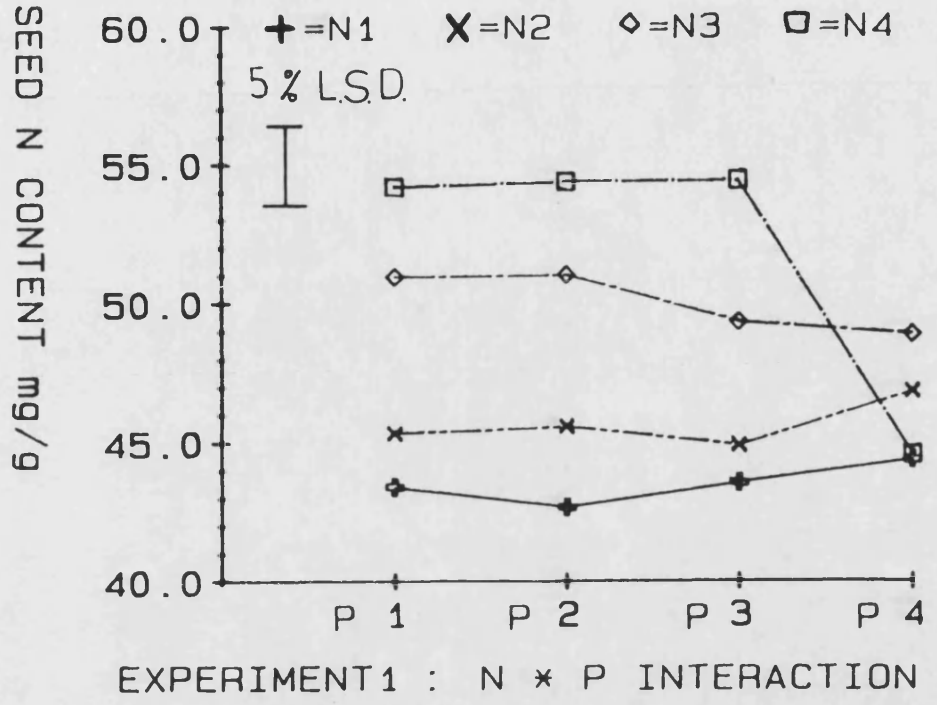

Figure 53. The effect of N and P interaction on the seeds' total nitrogen content.

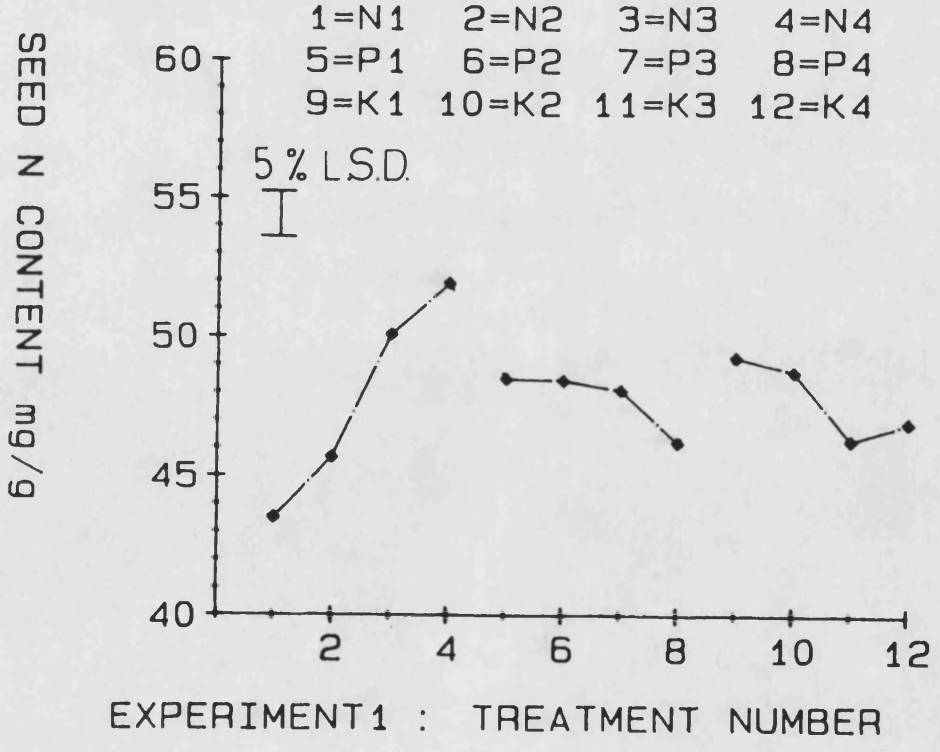

Figure 54. The main effect of N, P and K mineral nutrition levels on the seeds' total nitrogen content.

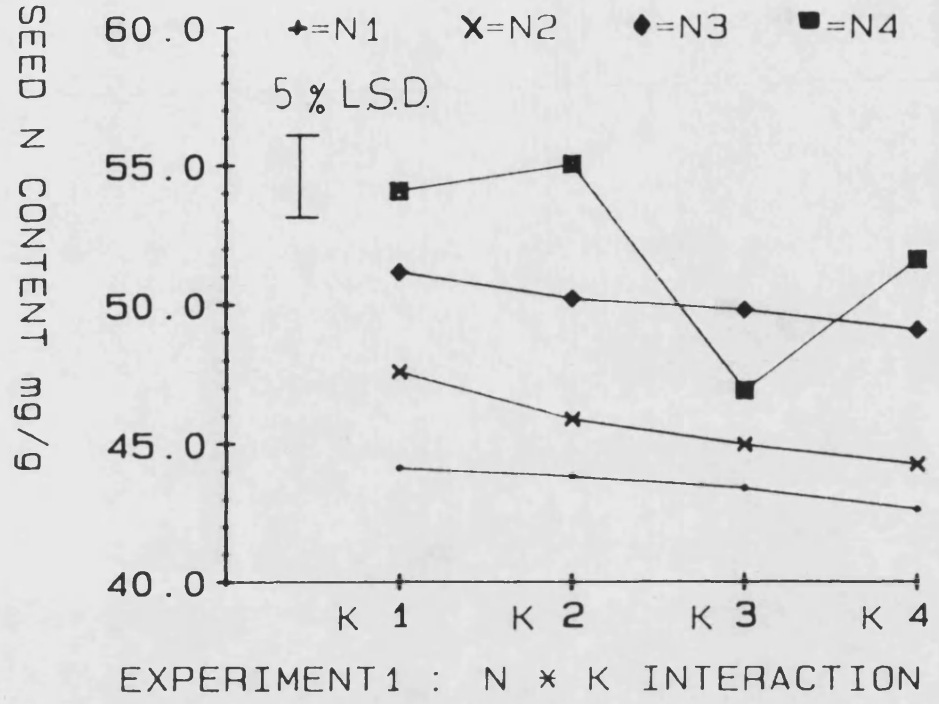

Figure 55. The effect of N and K interaction on the seeds' total nitrogen content.

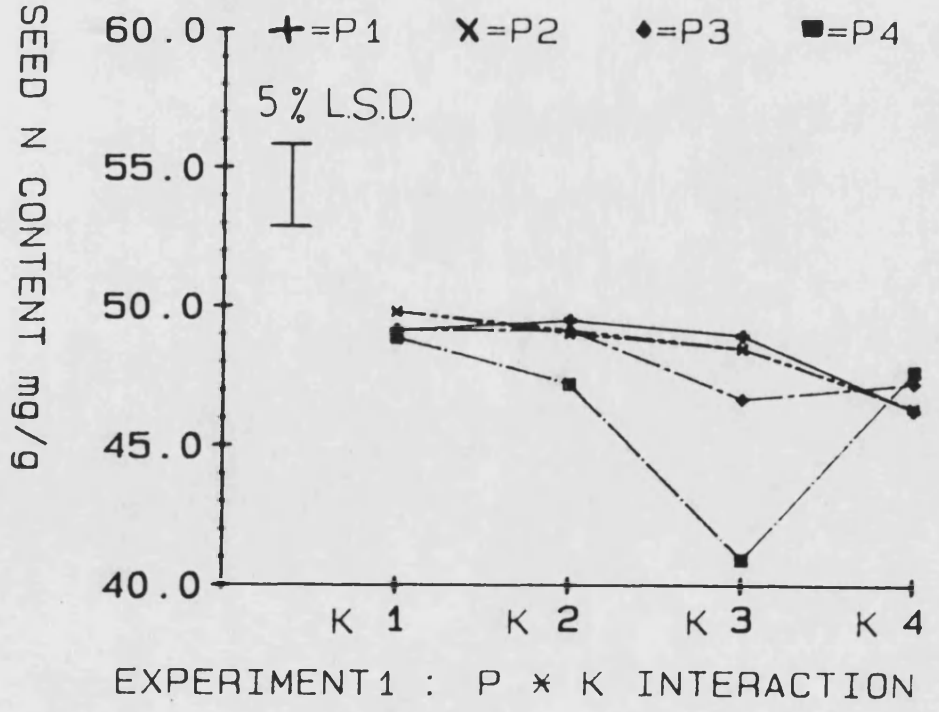

Figure 56. The effect of P and K interaction on the seeds' total nitrogen content.

As shown in Figure 54, the seeds' total N content increased with increasing N levels, and decreased with increasing P and K levels in this experiment and in the orders of $N_4 > N_3 > N_2 > N_1$, $P_1 > P_2 > P_3 > P_4$ and $K_1 > K_2 > K_4 > K_3$.

Figures 53, 55 and 56 show the effects of NP, NK and PK interactions on the seeds' total N content respectively. The highest seed N content in the interaction NP was achieved by N_4P_3 (54.38 g per g), NK interaction by N_4K_2 (55.01 mg per g) and PK interaction by K_1P_2 (49.79 mg per g) and the lowest in the interaction NP by the combination N_1P_2 (42.66 mg per g), NK Interaction by N_1K_4 (44.13 mg per g) and PK interaction by P_4K_3 (40.92 mg per g). In the three way NPK interaction the higest seed N content was achieved by the combination $N_4P_3K_2$ (57.50 mg per g) and the lowest by the combination $N_1P_2K_4$ (41.10 mg per g).

4.3.1.2 Experiment 2: Total seed Nitrogen content

The total seed nitrogen content was determined in seed samples (Section 3.2.1) from each treatment in order to examine the effect of N and P nutrition levels on seed N content and to attempt to establish a relationship between seed yield and quality. From the analysis of variance presented in Table 34, it can be seen that the levels of N, P and their interaction significantly affected the seed N content at the 0.1%, 5.0% and 0.1% significance levels respectively in this experiment.

As shown in Figure 57, the total seed N content increased significantly and that the levels of P have had very little effect from P_1 to P_3 and significantly decreased from P_3 to P_4 as indicated in the orders of $N_1 < N_2$ and $P_1 \simeq P_2 \simeq P_3 > P_4$ in this experiment.

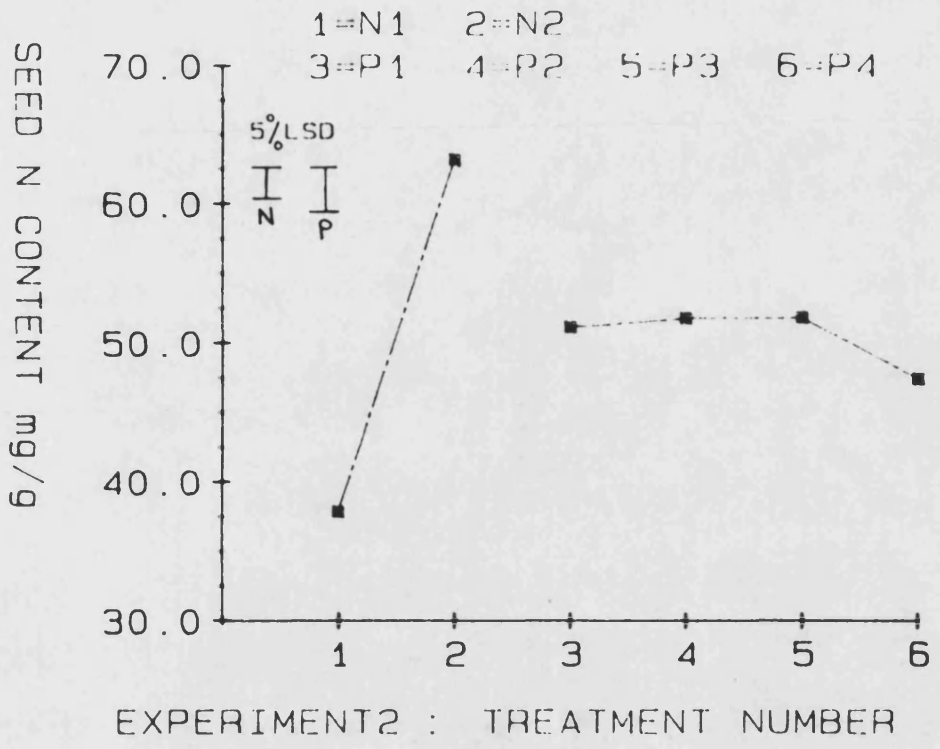

Figure 57. The effect of N and P mineral nutrition on the seeds' total nitrogen content.

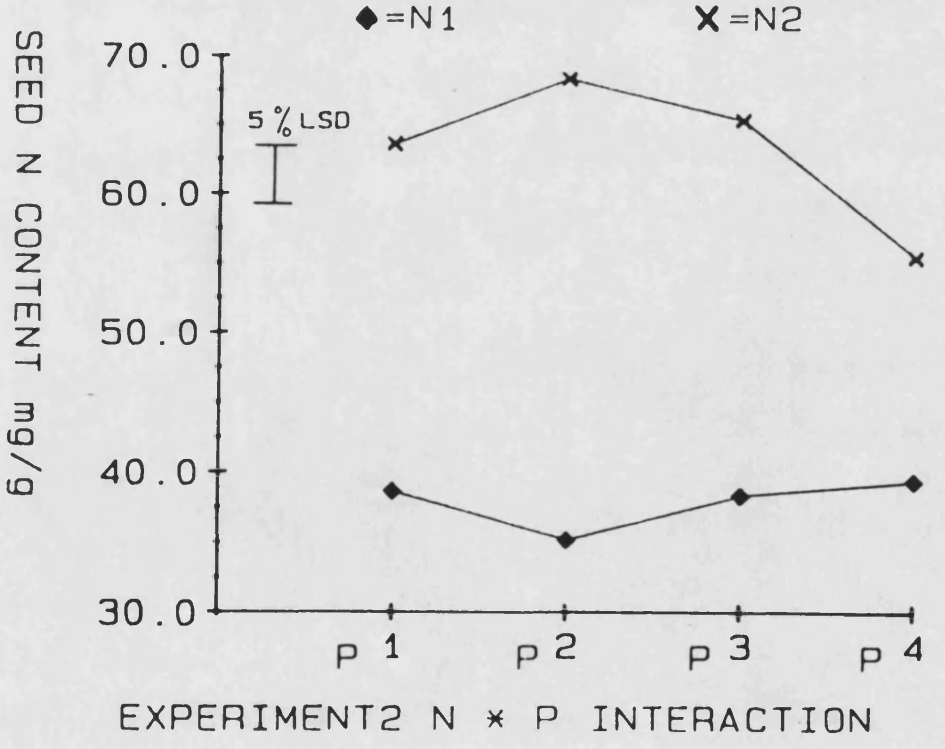

Figure 58. The effect of N and P interaction on the seeds' total nitrogen content.

Total nutrient levels (mg per plant)	N (mg per g)	Total nutrient levels (mg per plant)	(mg per g)
N_1 = 100	37.85	P_1 = 25	51.11
N_2 = 1000	63.157	P_2 = 250	51.72
		P_3 = 500	51.79
		P_4 = 1000	47.38

Significance levels:

N:	0.1%	P: 5.0%	N x P: 0.1%
5% LSD	N: 2.04	P: 2.88	N x P: 4.07

Table 34. The effect of N and P nutrition levels on total seed nitrogen content in Experiments 2.

Figure 58 shows the effect of N and P interaction on total seed nitrogen content. The highest seed N content was achieved by the combination N_2P_2 (68.31 mg per g) and the lowest by N_1P_2 (35.13 mg per g).

4.3.1.3 Experiment 3: Total seed Ntrogen Content

The total seed nitrogen content was determined in seed samples (Section 3.2.1) from each treatment in order to examine the main effect of N, P and K mineral nutrition levels on seed N content and to attempt to establish a relationship between seed yield and quality. From the analysis of variance presented in Table 35, it

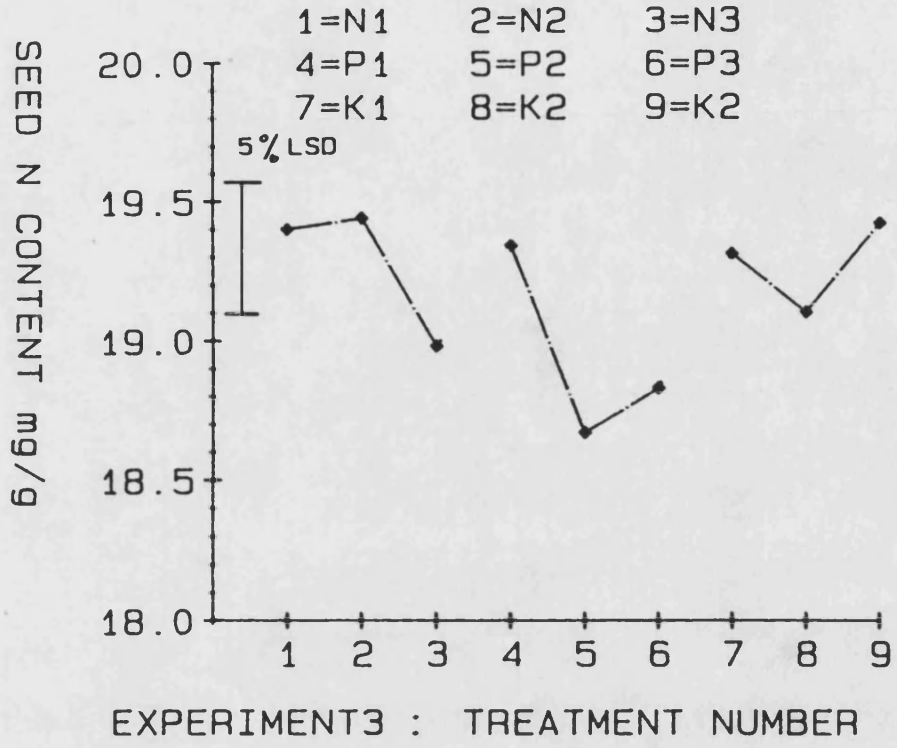

Figure 59. The main effect of N, P and K mineral nutrition level on seeds' total nitrogen content.

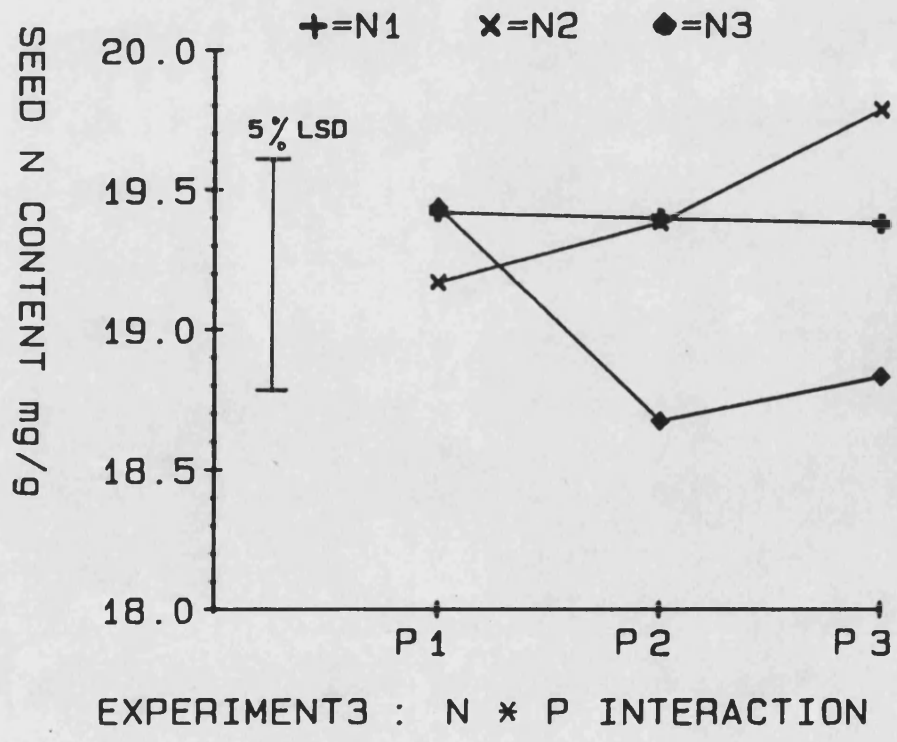

Figure 60. The effect of N and P interaction on seeds' total nitrogen content.

Total nutrient levels (kg per ha)	N (mg per g)	Total nutrient levels (kg per ha)	N (mg per (g)	Total nutrient levels (kg per ha)	N (mg per (g)
N_1 = 0	19.40	P_1 = 0	19.34	K_1 = 0	19.31
N_2 = 25	19.44	P_2 = 50	18.67	K_2 = 25	19.10
N_3 = 75	18.38	P_3 = 150	18.83	K_3 = 75	19.42

Significance levels:

N: N.S. N x P: N.S.

P: N.S. N x K: N.S. N x P x K: N.S.

K: N.S. P x K: N.S.

L.S.D. 5%
(N,P,K) = 0.48 (NxP,PxK,NxK) = 0.82 (N x P x K) = 1.43

Table 35. The effect of N, P and K mineral nutrition levels on total seed nitrogen content in Experiment 3.

can be seen that N, P and K and their interactions had no significant effect on total seed nitrogen contents.

Figure 59 shows the main effect of N, P and K nutrition levels on seed nitrogen content in this experiment.

Figure 60 shows the effect of N and P interaction on seed total nitrogen content.

4.3.1.4 Experiment 4: Total Seed Nitrogen Content

The total seed nitrogen content was determined in seed samples (Section 3.2.1) in each treatment in order to examine the effect of N and K mineral nutrition levels on seed N content and to attempt to establish a relationship between seed yield and quality.

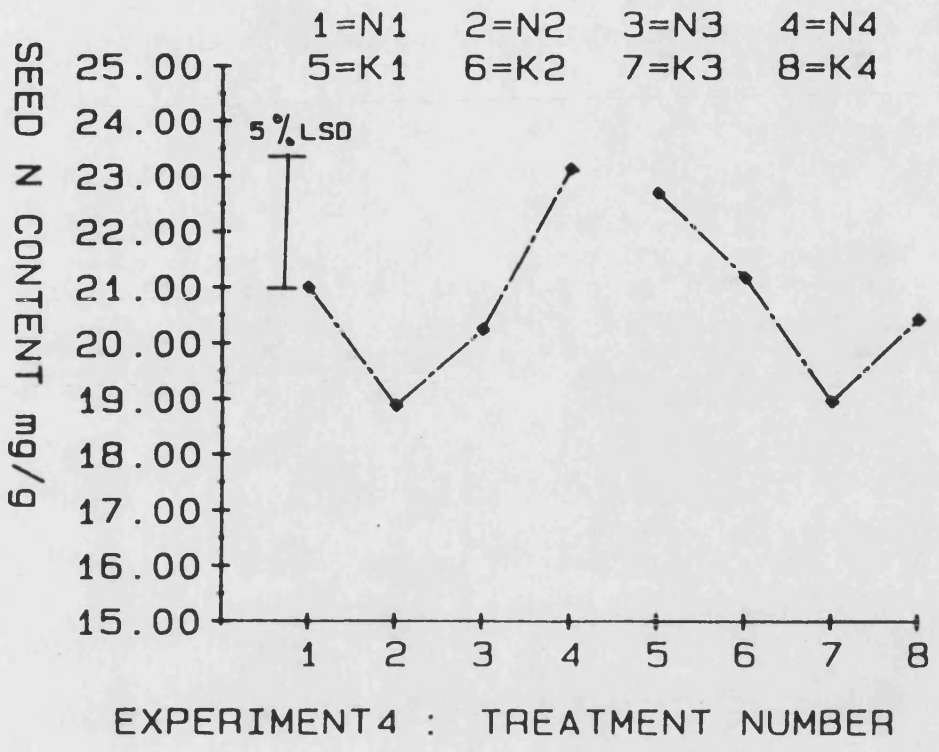

Figure 61. The main effect of N and K mineral nutrition levels on seeds' total nitrogen content.

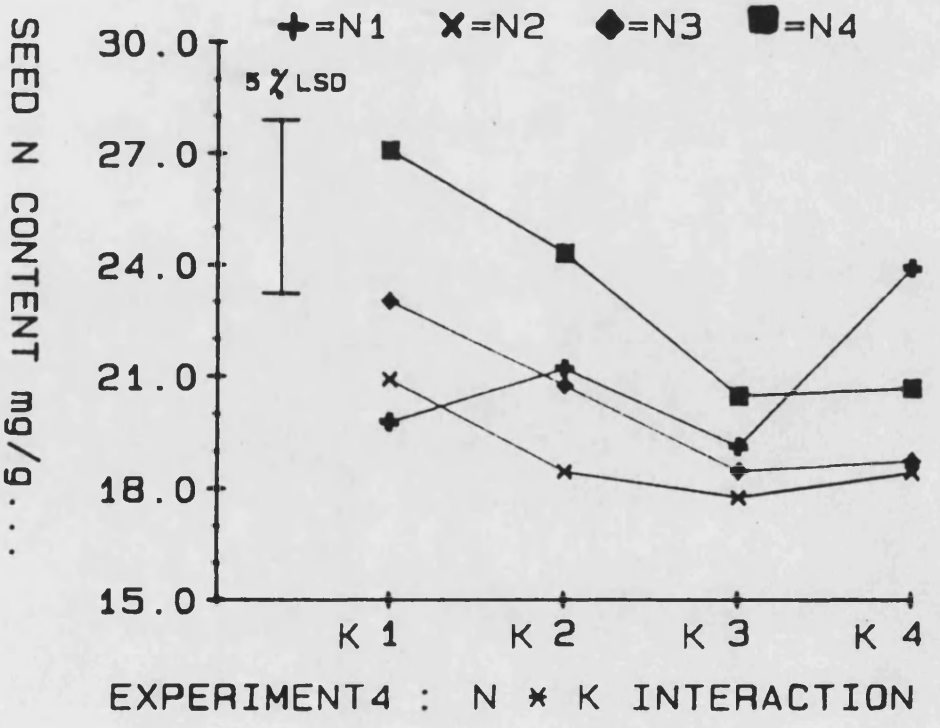

Figure 62. The effect of NK interaction on seeds' total nitrogen content.

Total nutrient levels (mg per plant)	N (mg per g)	Total nutrient levels (mg per plant)	N (mg per g)
N_1 = 0	21.00	K_1 = 0	22.70
N_2 = 100	18.88	K_2 = 50	21.18
N_3 = 500	20.25	K_3 = 250	18.95
N_4 = 1000	23.14	K_4 = 500	20.43

Significance levels:

N: 1.0% K: 5.0%, and their interaction Nx K: N.S.

5% LSD = 2.34

Table 36. The effect of N and K nutrition levels on total seed nitrogen content in Experiment 4.

From the analysis of variance presented in Table 36, it can be seen that N and K levels affected seed nitrogen content significantly at thie 1.0% and 5.0% levels respectively.

As shown in Figure 61 the total nitrogen content of the seed increased with increasing levels of N after an initial decrease from N_1 to N_2, in the order of $N_2 < N_1 < N_3 < N_4$, whereas increasing levels of K decreased seed N content up to K_3 with K_4 rising, in the order of $K_1 > K_2 > K_3 < K_4$ in this experiment.

4.3.2.1 Experiment 1: Total Seed Phosphorus Content

The total seed phosphorus content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N, P and K nutrition levels on seed P content and to attempt to establish a relationship between seed yield and quality.

Total nutrient levels (mg per plant)	P (mg per g)	Total Nutrient levels (mg per plant)	P (mg per g)	Total nutrient levels (mg per plant)	P (mg per g)
N_1 = 100	16.94	P_1 = 50	11.95	K_1 = 40	16.81
N_2 = 150	18.28	P_2 = 70	13.15	K_2 = 60	17.71
N_3 = 300	15.87	P_3 = 140	19.82	K_3 = 120	16.82
N_4 = 500	16.29	P_4 =210	22.45	K_4 = 180	16.03

Significance levels:

N: 0.1% N x P: 1.0%

P: 0.1% N x K: 1.0% N x P x K: 0.1%

K: 1.0% P x K: 0.1%

L.S.D. (N,P,K) = 0.84 (NxP,PxK,NxK) = 1.68 (N x P x K) = 3.36

Table 37. The effect of N, P and K mineral nutrition levels on total seed phosphorus in Experiment 1.

From the analysis of variance presented in Table 37, it can be seen that the levels of N,P and the interactions PK and NPK significantly affected the seed P content at the 0.1% significance level and that the levels of K and the interactions NP and NK at the 1.0% significance levels.

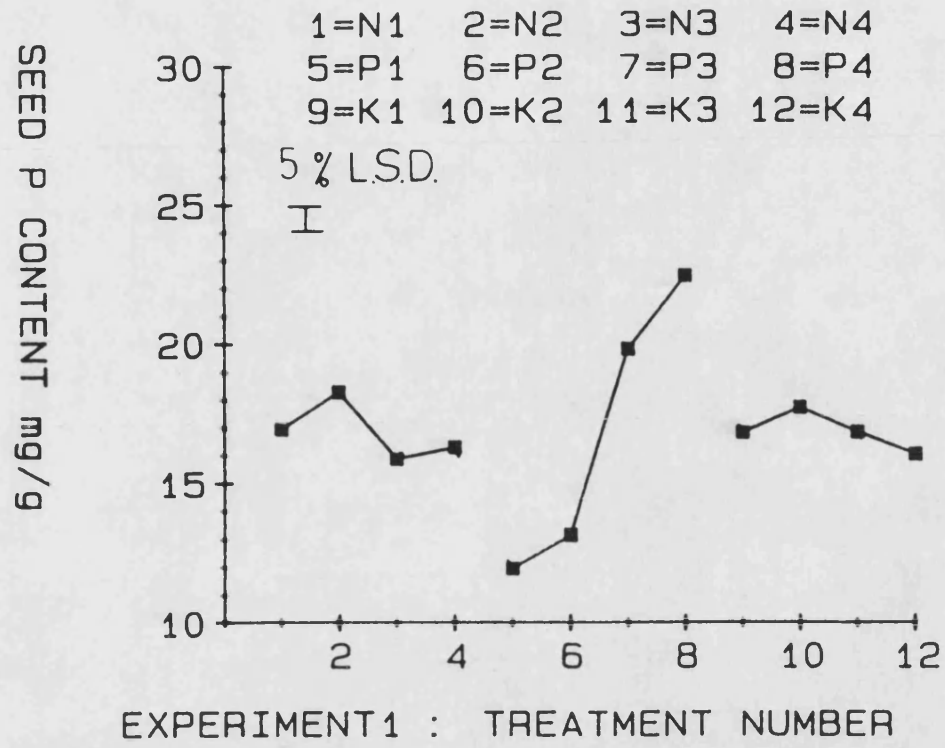

Figure 63. The main effect of N, P and K mineral nutrition level on seeds' total phosphorus content.

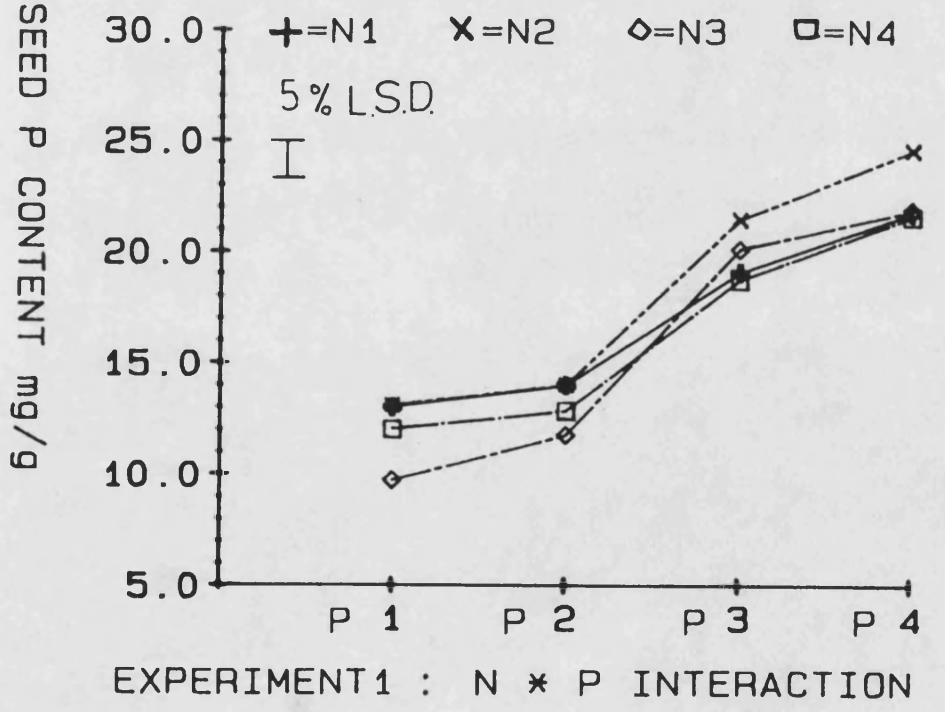

Figure 64. The effect of N and P interaction on the seeds' total phosphorus content.

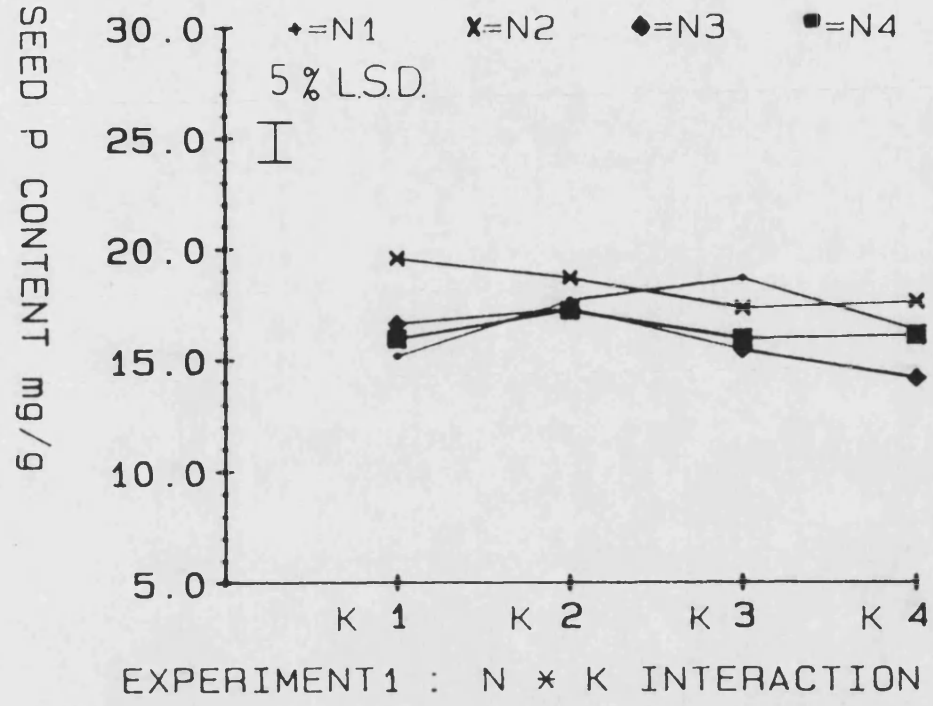

Figure 65. The effect of N and K interaction on the seeds' total phosphorus content.

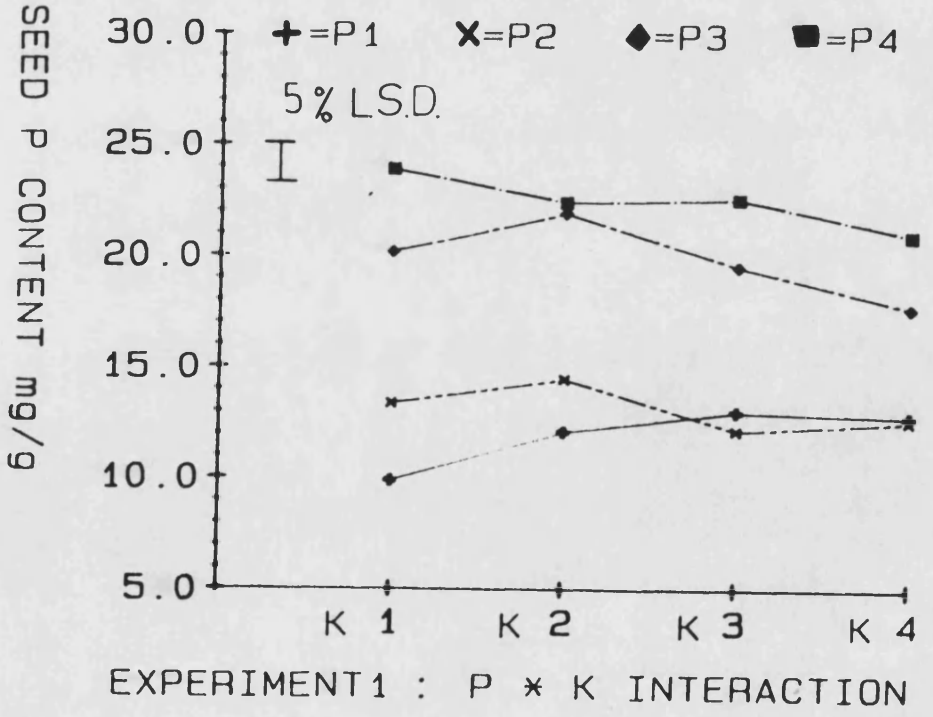

Figure 66. The effect of P and K interaction on the seeds' total phosphorus content.

As shown in Figure 63, the total seed P content decreased with increasing levels of N and K and it increased with increasing levels of P in this experiment and in the orders $N_2 > N_1 > N_4 > N_3$, $K_2 > K_1 > K_3 > K_4$ and $P_4 > P_3 > P_2 > P_1$.

Figures 64, 65 and 66 show the effects of NP, NK and PK interactions on the seeds' total P content. The highest seed P content was achieved by the combinations N_2P_4 (24.57 mg per g), N_2K_1 (19.56 mg per g) and K_1P_4 (23.88 mg per g) in the interactions NP, NK and PK respectively. The lowest seed P content was achieved by the combination P_1N_3 (9.72 mg per g), N_3K_4 (14.15 mg per g) and P_1K_1 (9.87 mg per g in the interactions NP, NK and PK respectively.

In the NPK interaction the highest seed P was achieved by the combination $N_2P_4K_1$ (27.6 mg per g) and the lowest by $N_3P_1K_2$ (8.9 mg per g).

4.3.2.2 Experiment 2: Total Seed Phosphorus Content

The total seed phosphorus content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N and P nutrition levels on seed P content and to attempt to establish a relationship between seed yield and quality. From the analysis of variance presented in Table 38, it can be seen that the levels of N and P significantly affected the seed P content at the 5.0% and 0.1% significance levels respectively in this experiment.

As shown in Figure 67, the total seed P content only slightly increased with increasing levels of N, but the increase is much more significant with increasing levels of P, especially from P_1 to P_2 as indicated in the orders of $N_2 > N_1$ and $P_4 > P_2 >> P_1$.

Figure 68 shows the effect of N and P interaction on total seed P content.

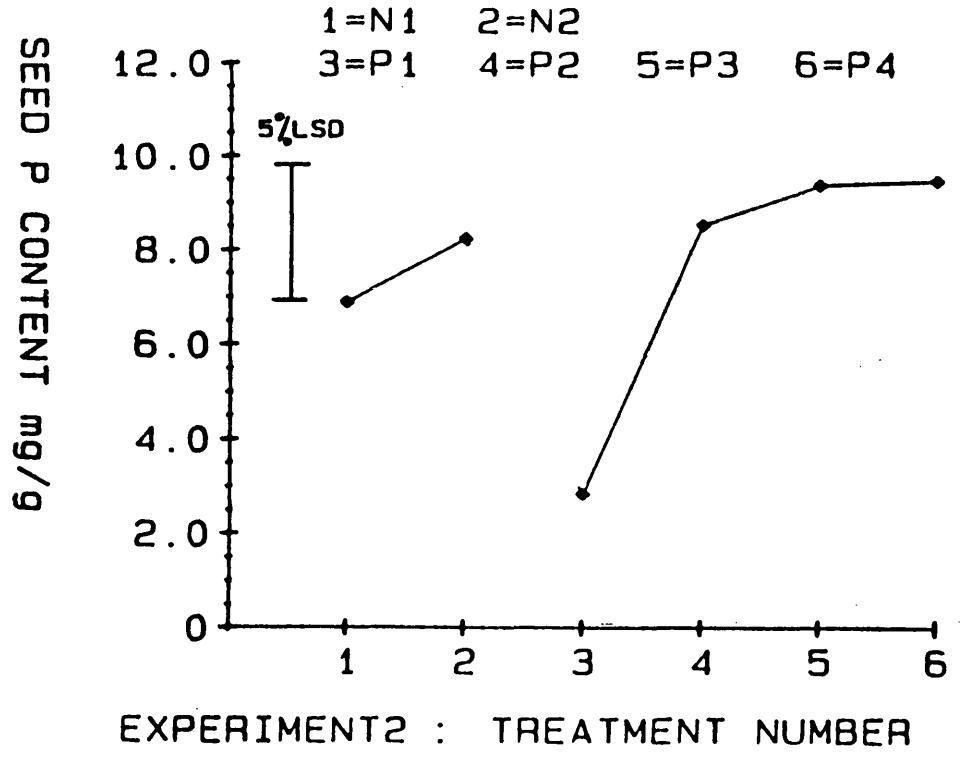

Figure 67. The effect of N and P mineral nutrition levels on seeds' total phosphorus content.

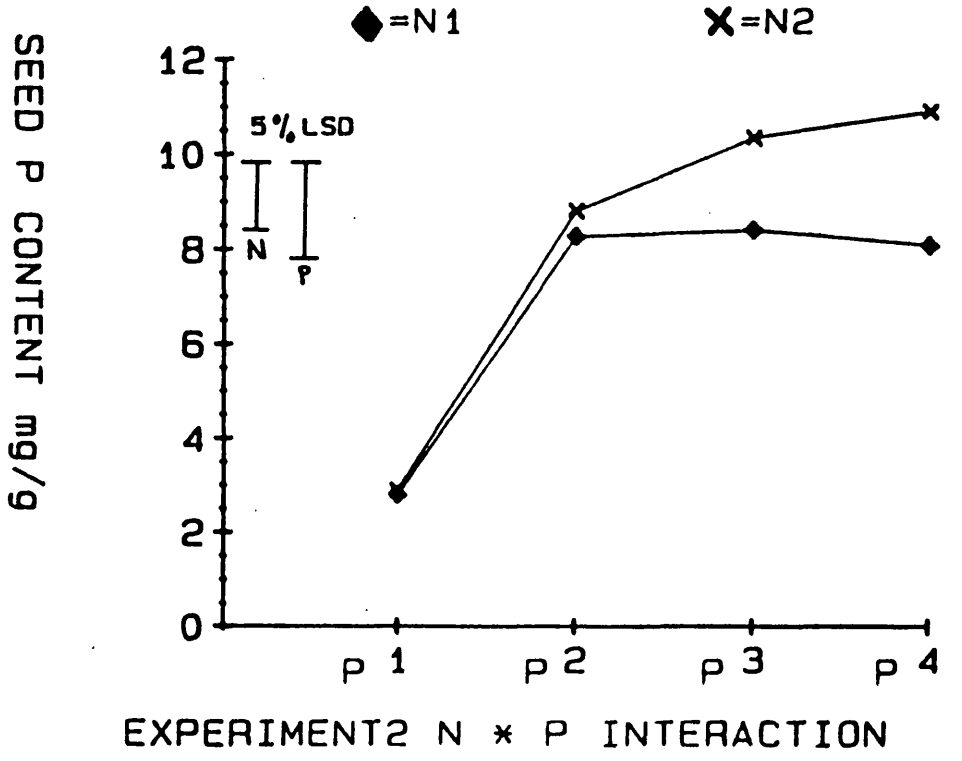

Figure 68. The effect of N and P interaction on seeds' total phosphorus content.

Total nutrient levels (mg per plant)	P (mg per g)	Total nutrient levels (mg per plant)	P(mg per g)
N_1 = 100	6.88	P_1 = 25	2.84
N_2 = 1000	8.24	P_2 = 250	8.53
		P_3 = 500	9.38
		P_4 = 1000	9.49

Significance levels:

N:	5.0%	P: 0.1%	N x P: N.S.
5% LSD	N: 1.41	P: 1.99	N x P: 2.82

Table 38. The effect of N and P nutrition levels on total seed phosphorus content in Experiment 2.

4.3.2.3 Experiment 3: Total Seed Phosphorus Content

The total seed phosphorus content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N, P and K mineral nutrition levels on seed P content and to attempt to establish a relationship between seed yield and quality. From the analysis of variance in Table 39 it can be seen that the seed phosphorus content was significantly affected by N and the interactions N x P and N x P x K at the 0.1%, 0.1% and 5.0% significance levels respectively.

As shown in Figure 69 the total seed phosphorus content decreased with increasing N levels in the order of $N_1 > N_2 > N_3$.

Figure 70 shows the effect of N x P interaction on seed phosphorus content. The combination with the highest seed P content

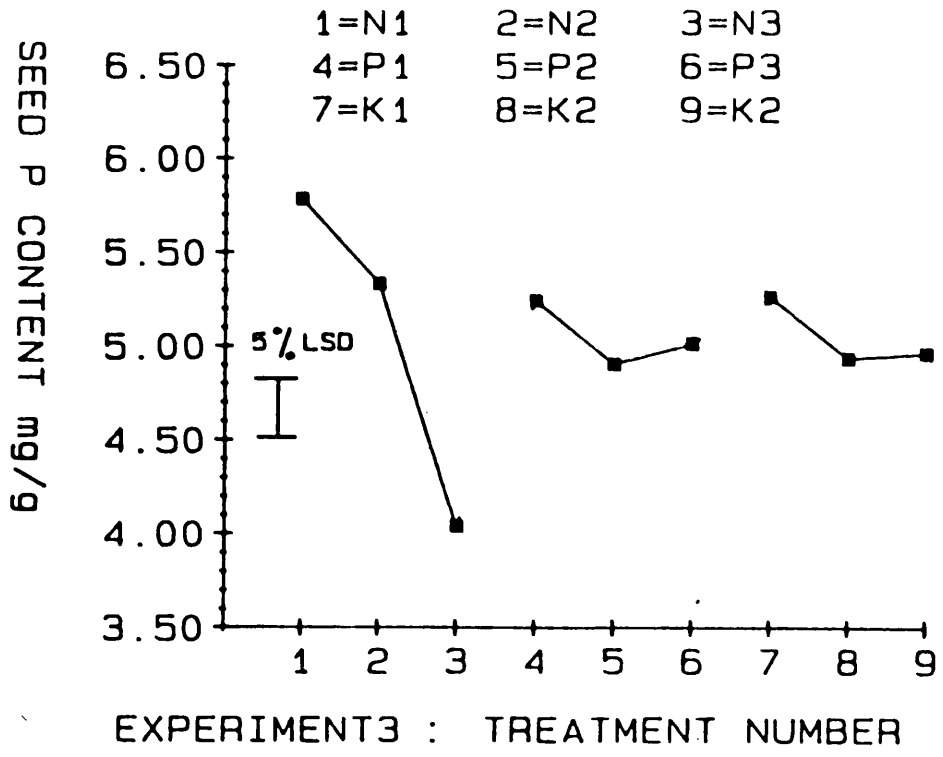

Figure 69. The main effect of N, P and K mineral nutrition on seeds' total phosphorus content

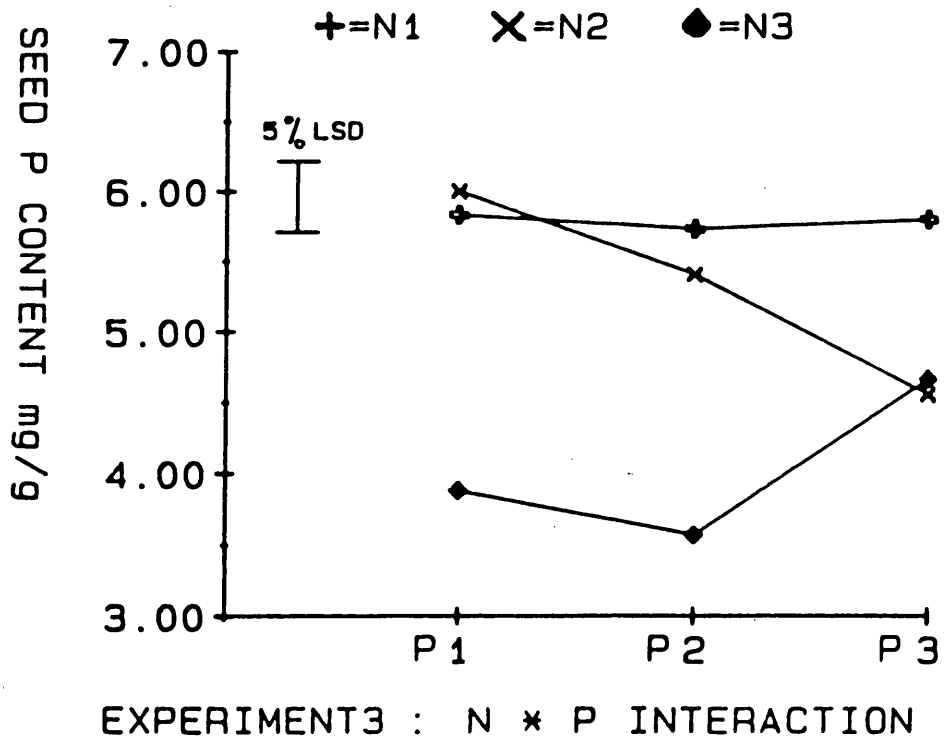

Figure 70. The effect of N x P interaction on seeds' total phosphorus content.

Total nutrient levels (kg per ha)	P (mg per g)	Total nutrient levels (kg per ha)	P (mg per (g)	Total nutrient levels (kg per ha)	P (mg per (g)
$N_1 = 0$	5.78	$P_1 = 0$	5.24	$K_1 = 0$	5.26
$N_2 = 25$	5.33	$P_2 = 50$	4.90	$K_2 = 25$	4.93
$N_3 = 75$	4.04	$P_3 = 150$	5.01	$K_3 = 75$	4.96

Significance levels:

N: 0.1% N x P: 0.1%

P: N.S. N x K: N.S. N x P x K: 5.0%

K: N.S. P x K: N.S.

L.S.D. 5%
(N,P,K) = 0.29 (NxP,PxK,NxK) = 0.51 (N x P x K) = 0.88

Table 35. The effect of N, P and K mineral nutrition levels on total seed phosphorus content in Experiment 3.

was N_2P_1 (6.02 mg per g) and the lowest by N_3P_2 (3.57 mg per g).

In the 3 way interaction (N x P x K), the combination with the highest seed P content was $N_1P_1K_1$ (6.25 mg per g) and the lowest by $N_3P_2K_2$ (3.05 mg per g).

4.3.2.4 Experiment 4: Total Seed Phosphorus Content

The total seed phosphorus content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N and K nutrition levels on seed P content and to attempt to establish a relationship between seed yield and quality. From the analysis of variance presented in Table 40, it can be seen that N, K

Total nutrient levels (mg per plant)	P (mg per g)	Total nutrient levels (mg per plant)	P (mg per g)
N_1 = 0	5.61	K_1 = 0	5.47
N_2 = 100	5.43	K_2 = 50	5.10
N_3 = 500	5.29	K_3 = 250	5.41
N_4 = 1000	4.94	K_4 = 500	5.29

Significance levels:

N: N.S. K: N.S., and their interaction Nx K: N.S.

5% LSD = 0.64

Table 40. The effect of N and K nutrition levels on total seed phosphorus content in Experiment 4.

and their interaction N x K had no significant effect on seeds' total phosphorus content.

Figure 71 shows the main effect of N and K nutrition upon seed phosphorus content.

Figure 72 shows the effect of NK interaction on seeds' total phosphorus content.

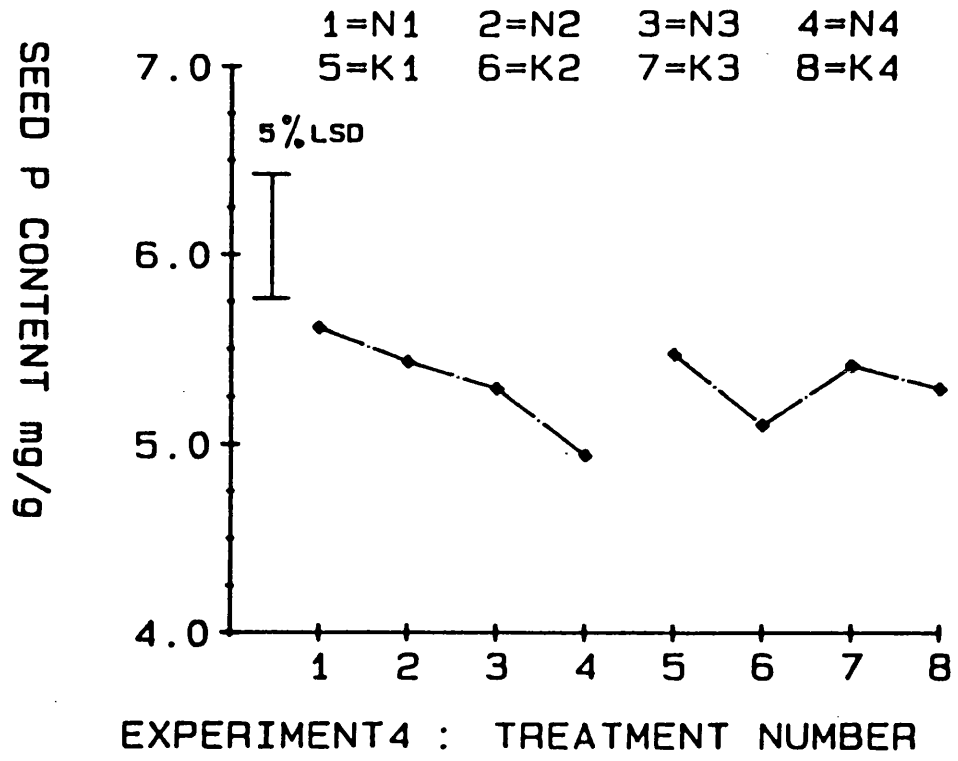

Figure 71. The main effect of N and K mineral nutrition levels on seeds' total phosphorus content.

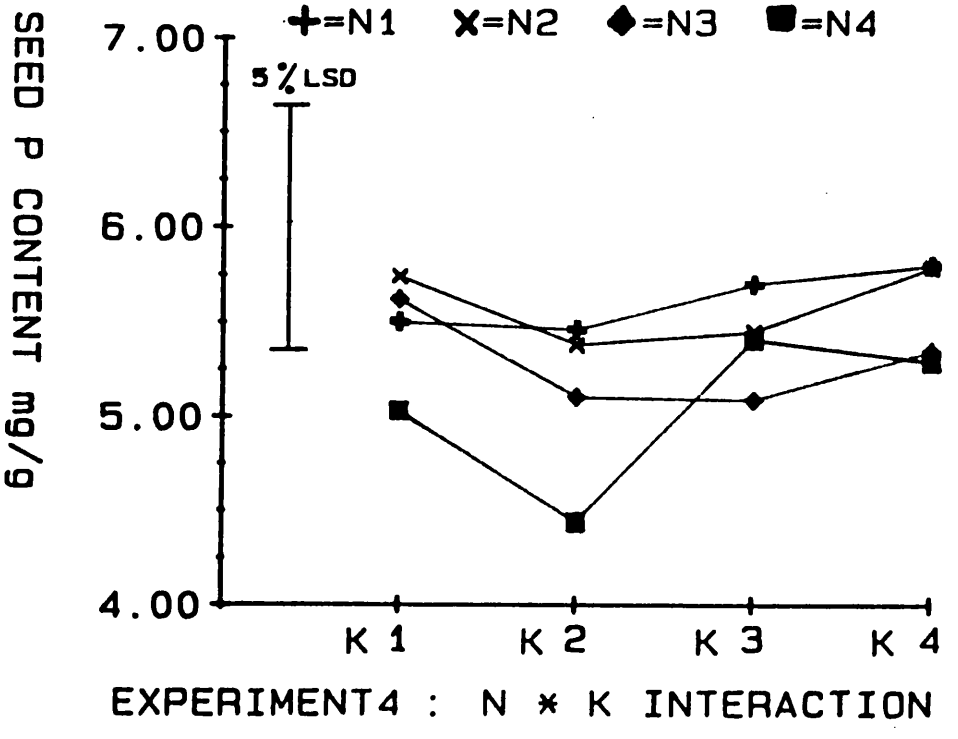

Figure 72. The effect of N K interaction on seeds' total phosphorus content.

4.3.3.1 Experiment 1: Total Seed Potassium Content

The total seed potassium content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N, P and K nutrition levels on seed K content and to attempt to establish a relationship between seed yield and quality.

Total nutrient levels (mg per plant)	K (mg per g)	Total Nutrient levels (mg per plant)	K (mg per g)	Total nutrient levels (mg per plant)	K (mg per g)
N_1 = 100	22.12	P_1 = 50	21.21	K_1 = 40	21.76
N_2 = 150	21.51	P_2 = 70	21.33	K_2 = 60	22.66
N_3 = 300	21.27	P_3 = 140	22.48	K_3 = 120	22.34
N_4 = 500	23.66	P_4 =210	21.79	K_4 = 180	22.14

Significance levels:

N: 0.1% N x P: 0.1%

P: 0.1% N x K: 0.1% N x P x K: 0.1%

K: 0.1% P x K: 0.1%

L.S.D. (N,P,K) = 0.443 (NxP,PxK,NxK) = 0.886 (N x P x K) = 1.772

Table 41. The effect of N, P and K mineral nutrition levels on total seed potassium content in Experiment 1.

From the analysis of variance presented in Table 41 it can be seen that the levels of N, P and K and the interactions NP, NK, PK and NPK significantly affected the total seed potassium content at 0.1% significance level.

As shown in Figure 73, the seed K content decreased with

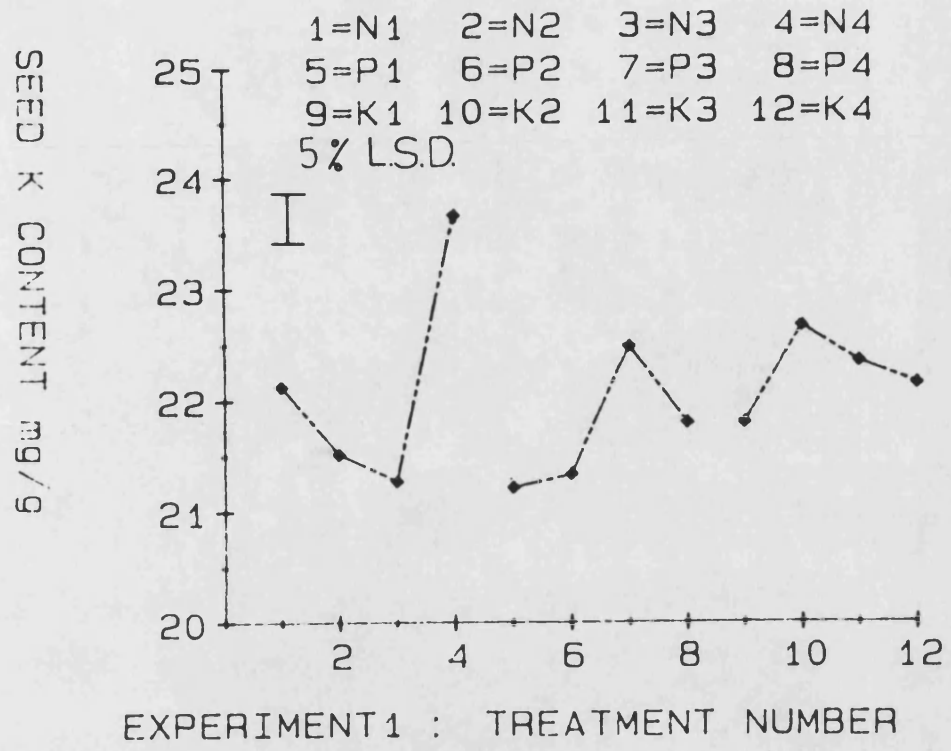

Figure 73. The main effect of N, P and K mineral nutrition levels on the seeds' total potassium content.

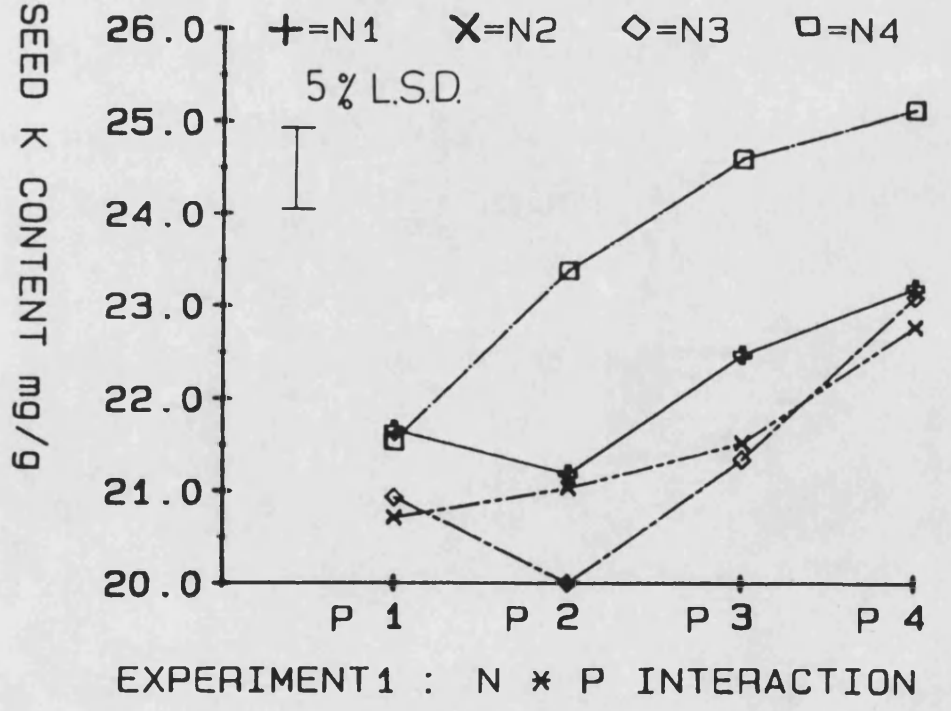

Figure 74. The effect of N and P interaction on the seeds' total potassium content.

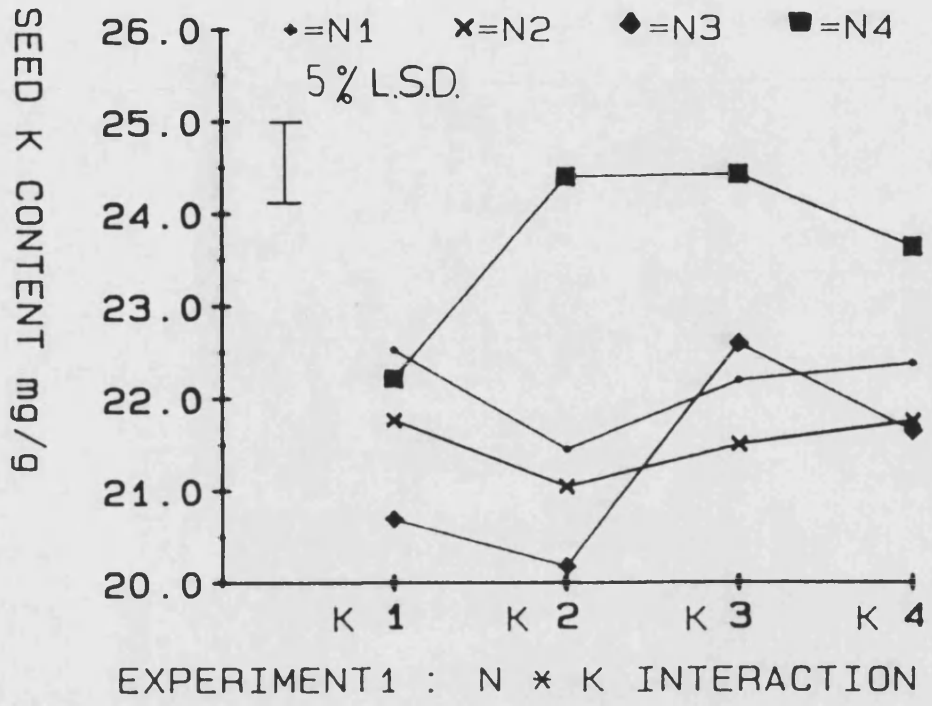

Figure 75. The effect of N and K interaction on the seeds' total potassium content.

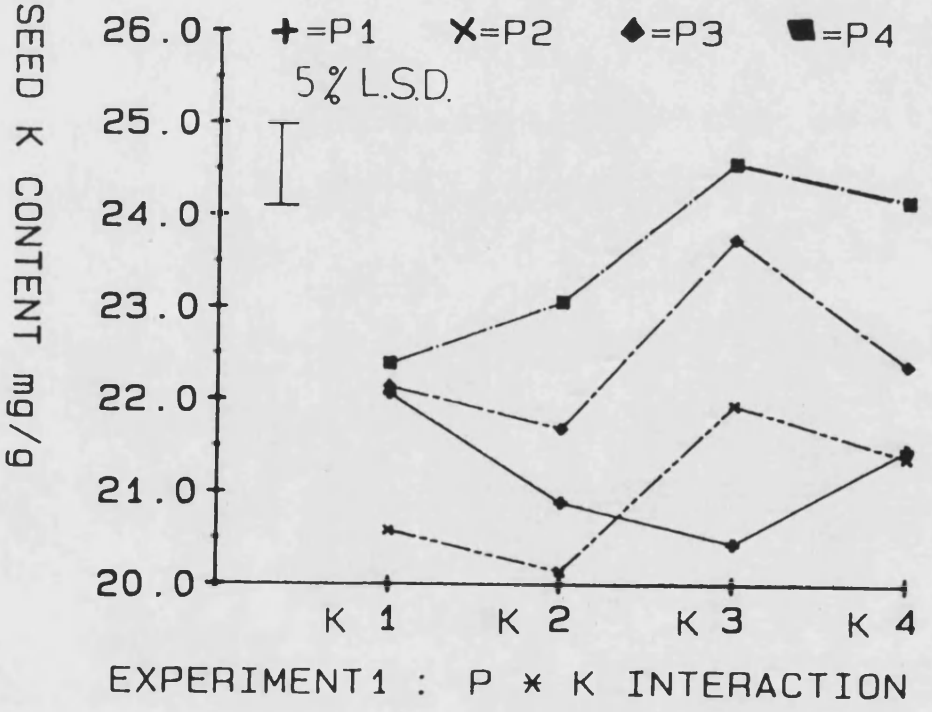

Figure 76. The effect of P and K interaction on the seeds' total potassium content.

increasing levels of N up to N_3 and then increased from N_3 to N_4, but it increased with increasing levels of P up to P_3 and then slightly decreased from P_3 to P_4. It also decreased with increasing levels of K after an initial increase from K_1 to K_2 in this experiment and in the orders of $N_4 > N_1 > N_2 > N_3$, $P_3 > P_4 > P_2 > P_1$, and $K_2 > K_3 > K_4 > K_1$.

Figures 74, 75 and 76 show the effect of NP, NK and PK interactions on the seed K content. The highest and the lowest seed K content in the interaction NP was achieved by N_4P_4 (25.12 mg per g) and N_3P_2 (19.72 mg per g), and in the NK interaction by N_4K_3 (24.41 mg per g) and N_3K_2 (20.18 mg per g) and in the PK interaction by P_4K_3 (24.56 mg per g) and P_2K_2 (20.14 mg per g).

In the N x P x K interaction the highest seed K content was achieved by $N_4P_4K_2$ (27.6 mg per g) and the lowest by $N_3P_2K_4$ (19.20 mg per g).

4.3.3.2 Experiment 2: Total Seed Potassium Content

The total seed potassium content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N and P nutrition levels on seed K content and to attempt to establish a relationship between seed yield and quality.From the analysis of variance presented in Table 42, it can be seen that the levels of N, P and their interaction NP significantly affected the total seed K content at high significance levels of 0.1% in this experiment.

As shown in Figure 77 seed K decreased with increasing levels of N but increased with increasing levels of K in this experiment and in the orders of $N_1 > N_2$ and $P_4 > P_3 > P_2 > P_1$.

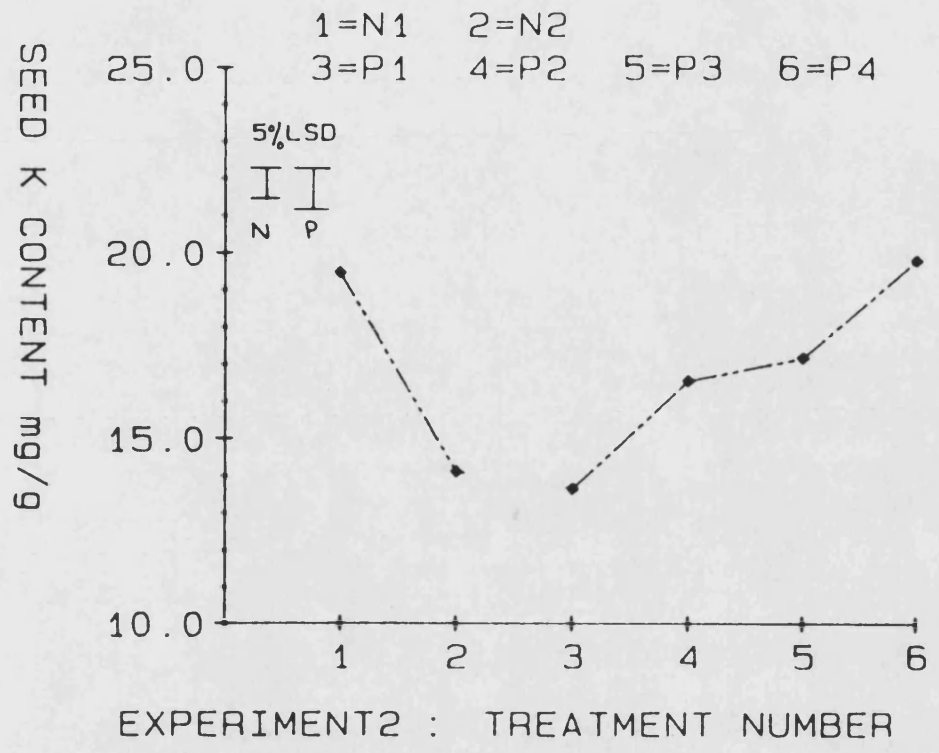

Figure 77. The main effect of N and P mineral nutrition levels on the seeds' total potassium content.

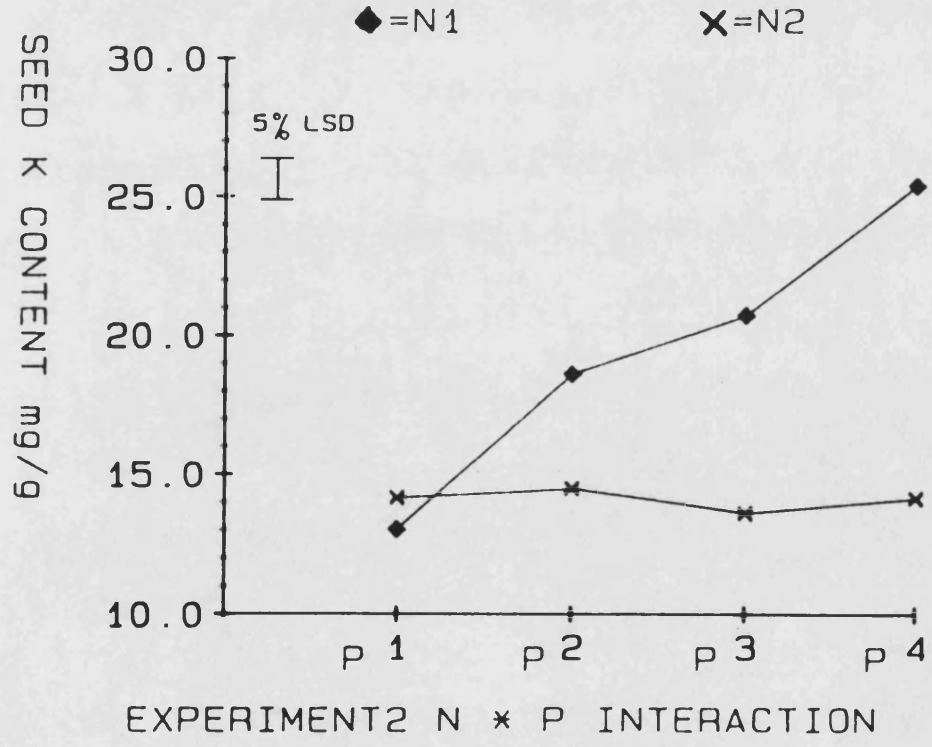

Figure 78. The effect of N and P interaction on seeds' total potassium content.

Total nutrient levels (mg per plant)	K (mg per g)	Total nutrient levels (mg per plant)	K (mg per g)
N_1 = 100	19.45	P_1 = 25	13.63
N_2 = 1000	14.09	P_2 = 250	16.54
		P_3 = 500	17.15
		P_4 = 1000	19.77

Significance levels:

N:	0.1%	P: 0.1%	N x P: 0.1%
5% LSD	N: 0.74	P: 1.05	N x P: 1.48

Table 42. The effect of N and P nutrition levels on total seed potassium content in Experiment 2.

Figure 78 shows the effect of N and P interaction on total seed K content. The highest seed K content was achieved by N_1P_4 (25.39 mg per g) and the lowest by N_1P_1 (13.01 mg per g).

4.3.3.3 Experiment 3: Total Seed Potassium Content

The total seed potassium content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N, P and K mineral nutrition levels on seeds' total potassium content and to attempt to establish a relationship between seed yield and seed quality. From the analysis of variance presented in Table 43, it can be seen that N, P and their interaction (N x P) levels affected seed potassium content significantly at 0.1%, 5.0% and 0.1% respectively.

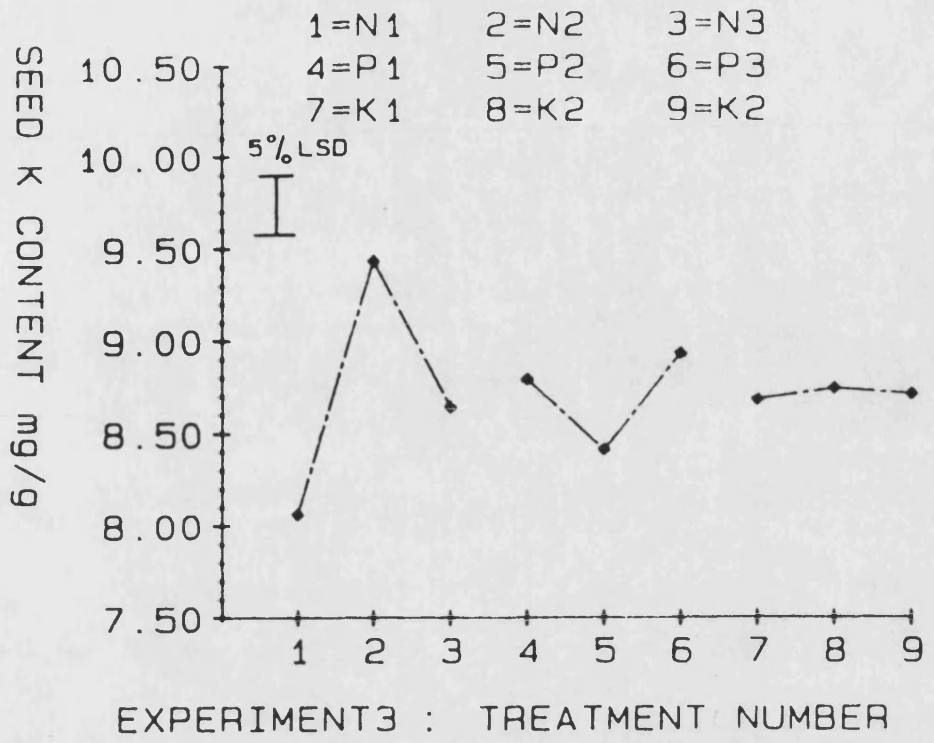

Figure 79. The main effect of N, P and K mineral nutrition levels on seeds' total potassium content.

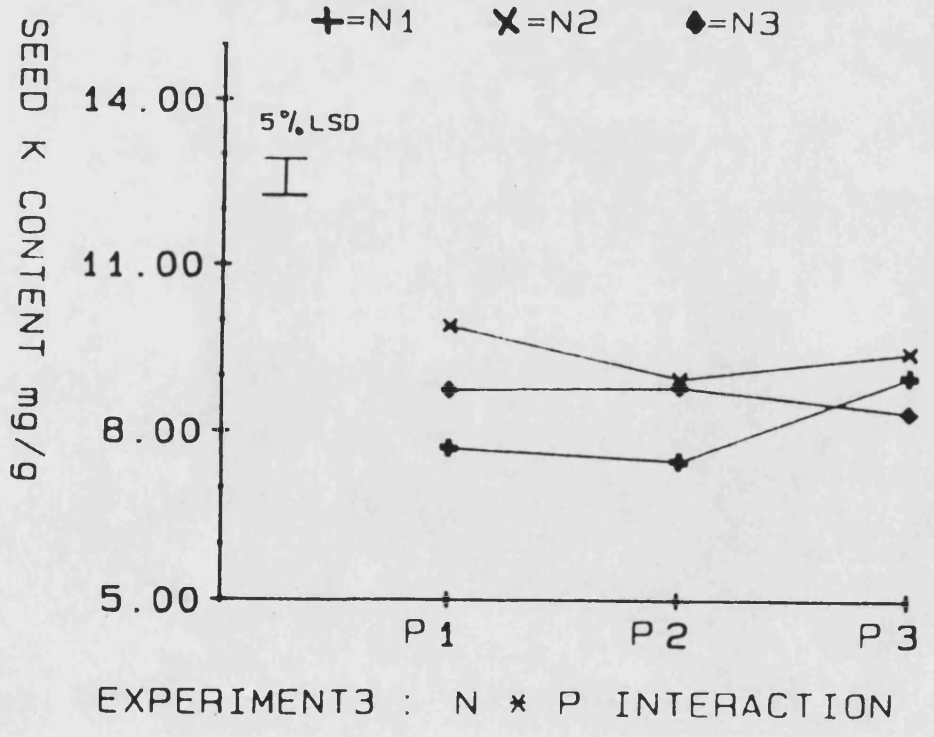

Figure 80. The effect of N x P interaction on seeds' total potassium content.

Total nutrient levels (kg per ha)	K (mg per g)	Total nutrient levels (kg per ha)	K (mg per (g)	Total nutrient levels (kg per ha)	K (mg per (g)
N_1 = 0	8.06	P_1 = 0	8.79	K_1 = 0	8.68
N_2 = 25	9.43	P_2 = 50	8.41	K_2 = 25	8.74
N_3 = 75	8.64	P_3 = 150	8.93	K_3 = 75	8.71

Significance levels:

N: 0.1% N x P: 0.1%

P: 5.0% N x K: N.S. N x P x K: N.S.

K: N.S. P x K: N.S.

L.S.D. 5%
(N,P,K) = 0.34 (NxP,PxK,NxK) = 0.59 (N x P x K) = 1.02

Table 43. The effect of N, P and K mineral nutrition levels on total seed potassium content in Experiment 3.

As shown in Figure 79, the seed potassium content is affected by the levels of N in the order of $N_2 > N_3 > N_1$ and by the levels of P: $P_3 > P_1 > P_2$ in this experiment.

Figure 80 shows the effect of N and P interaction on total seed potassium content. The highest seed potassium content was achieved by the combination N_2P_1 (9.91 mg per g) and the lowest by N_1P_2 (7.47 mg per g).

4.3.3.4 Experiment 4: Total Seed Potassium Content

The total seed potassium content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the

effect of N and K nutrition levels on seeds' total potassium content and to attempt to establish a relationship between seed yield and seed quality. From the analysis of variance presented in Table 44, it can

Total nutrient levels (mg per plant)	K (mg per g)	Total nutrient levels (mg per plant)	K (mg per g)
N_1 = 0	9.80	K_1 = 0	6.84
N_2 = 100	9.54	K_2 = 50	8.19
N_3 = 500	8.36	K_3 = 250	10.19
N_4 = 1000	7.85	K_4 = 500	10.32

Significance levels:

N: 0.1% K: 0.1%, and their interaction Nx K: 5.0%

5% LSD = 0.53

Table 44. The effect of N and K nutrition levels on total seed potassium content in Experiment 4.

be seen that N, K and their interaction levels affected seed potassium content significantly at 0.1%, 5.0% and 5.0% respectively.

As shown in Figure 81, the seed potassium content decreased with increasing levels of N and that it increased with increasing levels of K in the orders of $N_1 > N_2 > N_3 > N_4$ and $K_1 < K_2 < K_3 < K_4$ in this experiment.

Figure 82 shows the effect of N and K interaction on total seed potassium content. The highest seed potassium content was achieved by the combination N_1K_4 (11.14 mg per g) and the lowest by N_4K_1 (5.22 mg per g).

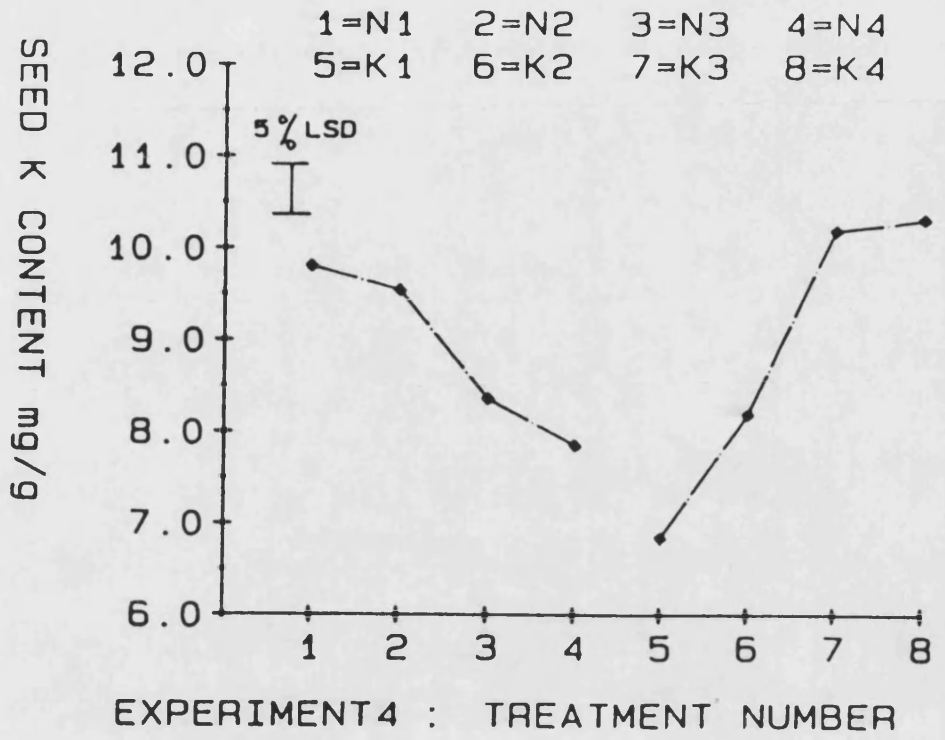

Figure 81. The main effect of N and K mineral nutrition levels on seeds' total potassium content.

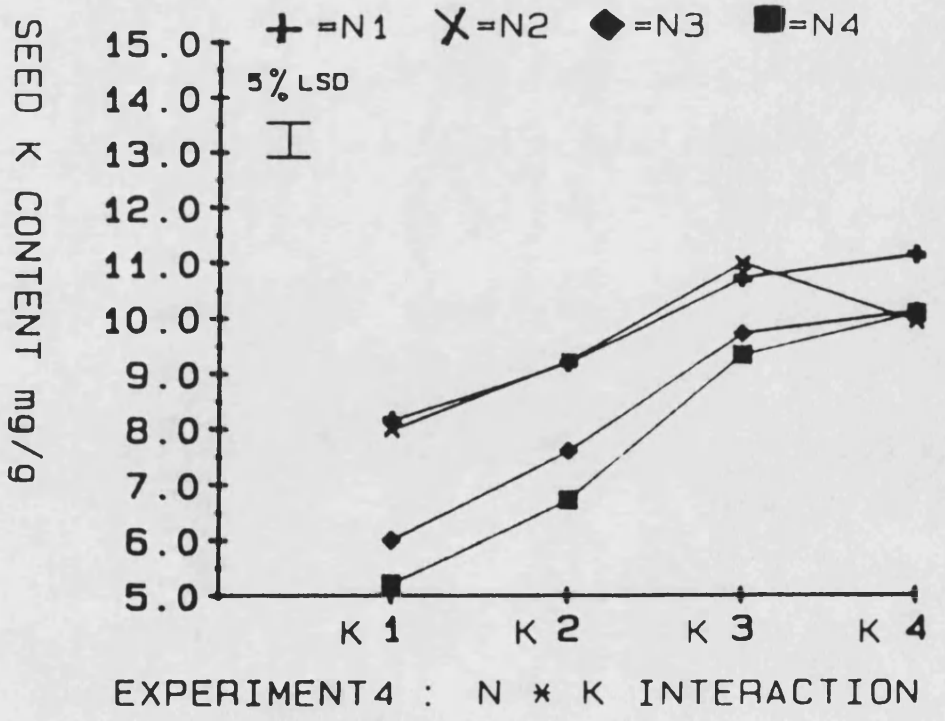

Figure 82. The effect of N and K interaction on seeds' total potassium content.

4.3.4.1 Experiment 1: Total Seed Magnesium Content

The total seed magnesium content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N, P and K nutrition levels on seed Mg content and to attempt to establish a relationship between seed yield and quality.

Total nutrient levels (mg per plant)	Mg (mg per g)	Total Nutrient levels (mg per plant)	Mg (mg per g)	Total nutrient levels (mg per plant)	Mg (mg per g)
N_1 = 100	5.98	P_1 = 50	5.97	K_1 = 40	6.02
N_2 = 150	5.83	P_2 = 70	6.01	K_2 = 60	6.06
N_3 = 300	5.79	P_3 = 140	6.09	K_3 = 120	5.83
N_4 = 500	6.33	P_4 =210	5.97	K_4 = 180	6.05

Significance levels:

N: 0.1%	N x P: N.S.	
P: N.S.	N x K: N.S.	N x P x K: N.S.
K: N.S.	P x K: N.S.	
L.S.D. (N,P,K) = 0.218	(NxP,PxK,NxK) = 0.435	(N x P x K) = 0.870

Table 45. The effect of N, P and K mineral nutrition levels on total seed magnesium content in Experiment 1.

From the analysis of variance presented in Table 45, it can be seen that only the levels of N significantly affected the seeds' total Mg content at the 0.1% significance level.

As shown in Figure 83, the seeds' Mg content decreased with increasing levels of N up to N_3 which then rose from N_3 to N_4 in this

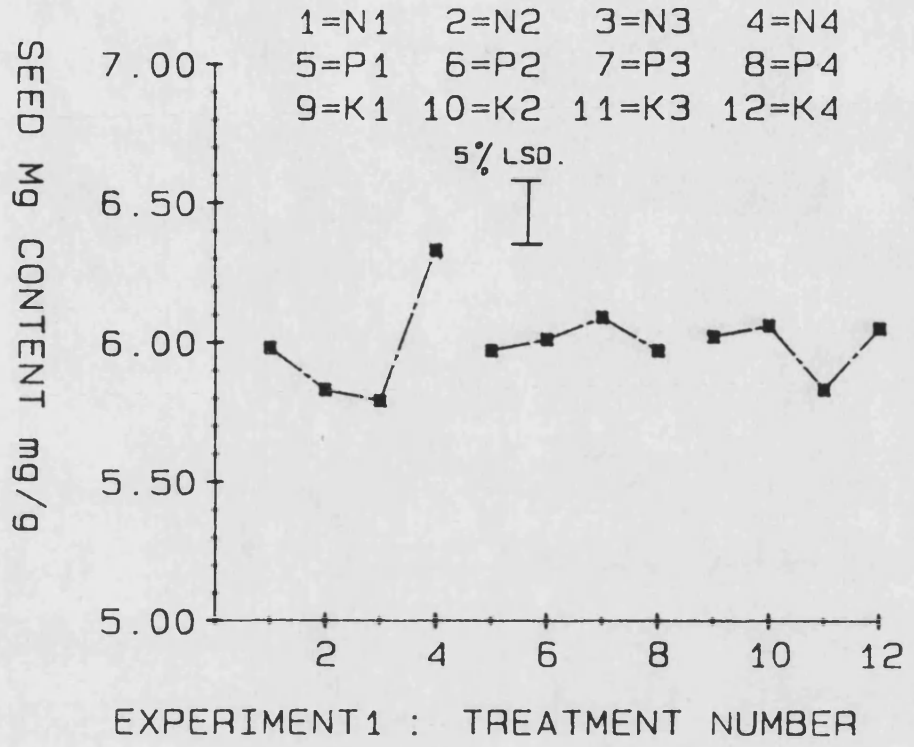

Figure 83. The main effect of N, P and K mineral nutrition levels on seeds' total magensium content.

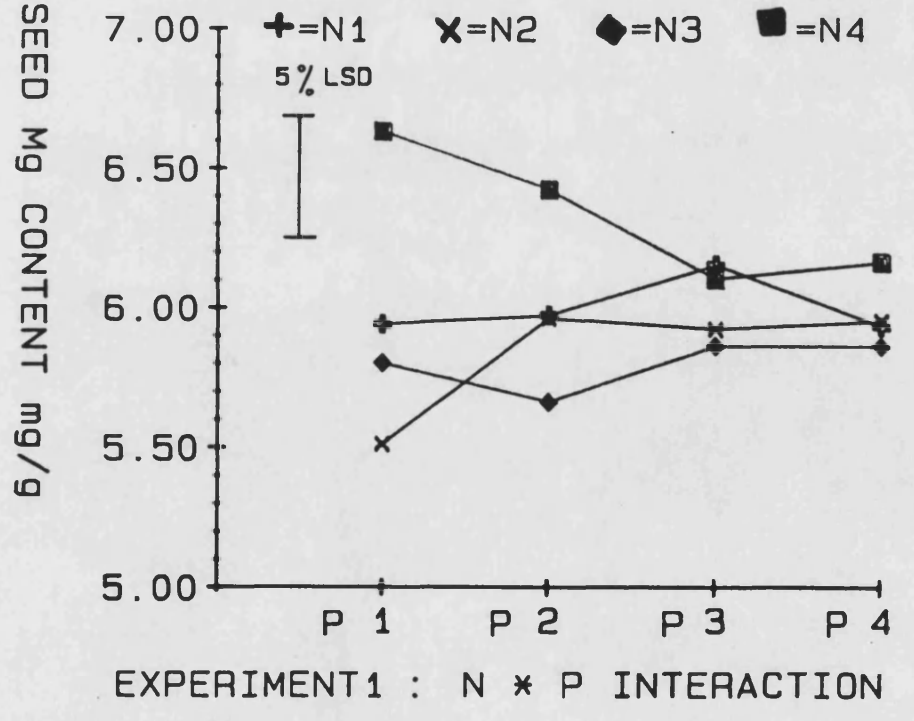

Figure 84. The effect of N and P interaction levels on seeds' total magnesium content.

experiment, and in the order of $N_4 > N_1 > N_2 > N_3$.

Figure 84 shows the effect of N and P interaction on seeds' total magensium content.

4.3.4.2 Experiment 2: Total Seed Magnesium Content

Total seed magnesium content was determined in samples of seeds (Section 3.2.2) from each treatment in order to examine the effect of N and P nutrition levels on seed magensium content and to attempt to establish a relationship between seed yield and qualty.

Total nutrient levels (mg per plant)	Mg (mg per g)	Total nutrient levels (mg per plant)	Mg(mg per g)
N_1 = 100	1.93	P_1 = 25	1.93
N_2 = 1000	2.51	P_2 = 250	2.18
		P_3 = 500	2.25
		P_4 = 1000	2.51

Significance levels:

N:	0.1%	P: 0.1%	N x P: 1.0%
5% LSD	N: 0.093	P: 0.130	N x P: 0.190

Table 46. The effect of N and P nutrition levels on total seed magnesium content in Experiment 2.

From the analysis of variance presented in Table 46, it can be seen that the levels of N, P and their interaction significantly affected the seed Mg content at the 0.1%, 0.1% and 1.0% significance levels

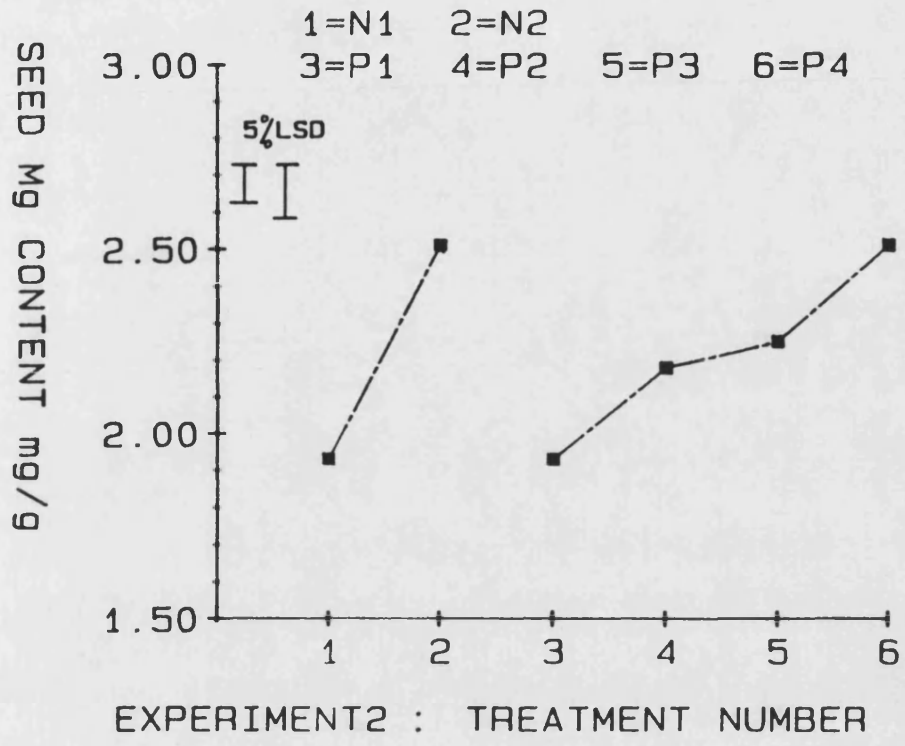

Figure 85. The effect of N and P mineral nutrition levels on seeds' total magnesium content.

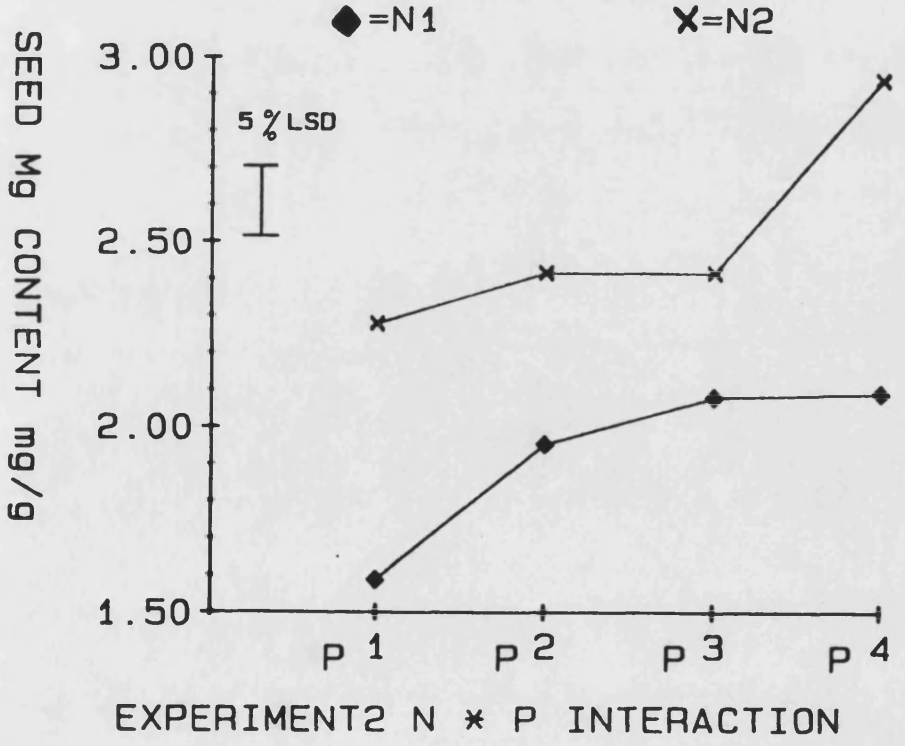

Figure 86. The effect of N and P interaction on seeds' total magnesium content.

respectively.

As shown in Figure 85, the total seed Mg content increased with increasing levels of N and also increased with increasing levels of P in the orders of $N_2 > N_1$ and $P_4 > P_3 > P_2 > P_1$ in this experiment.

4.3.4.3 Experiment 3: Total Seed Magnesium Content

The total seed magnesium content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N, P and K mineral nutrition levels on seed Mg content and to attempt to establish a relationship between seed yield and quality.

Total nutrient levels (kg per ha)	Mg (mg per g)	Total nutrient levels (kg per ha)	Mg (mg per (g)	Total nutrient levels (kg per ha)	Mg (mg per (g)
$N_1 = 0$	1.23	$P_1 = 0$	1.22	$K_1 = 0$	1.18
$N_2 = 25$	1.21	$P_2 = 50$	1.14	$K_2 = 25$	1.27
$N_3 = 75$	1.23	$P_3 = 150$	1.30	$K_3 = 75$	1.23

Significance levels:

N: N.S. N x P: N.S.

P: N.S. N x K: N.S. N x P x K: N.S.

K: N.S. P x K: N.S.

L.S.D. 5%
(N,P,K) = 0.143 (NxP,PxK,NxK) = 0.248 (N x P x K) = 0.429

Table 47. The effect of N, P and K mineral nutrition levels on total seed magnesium content in Experiment 3.

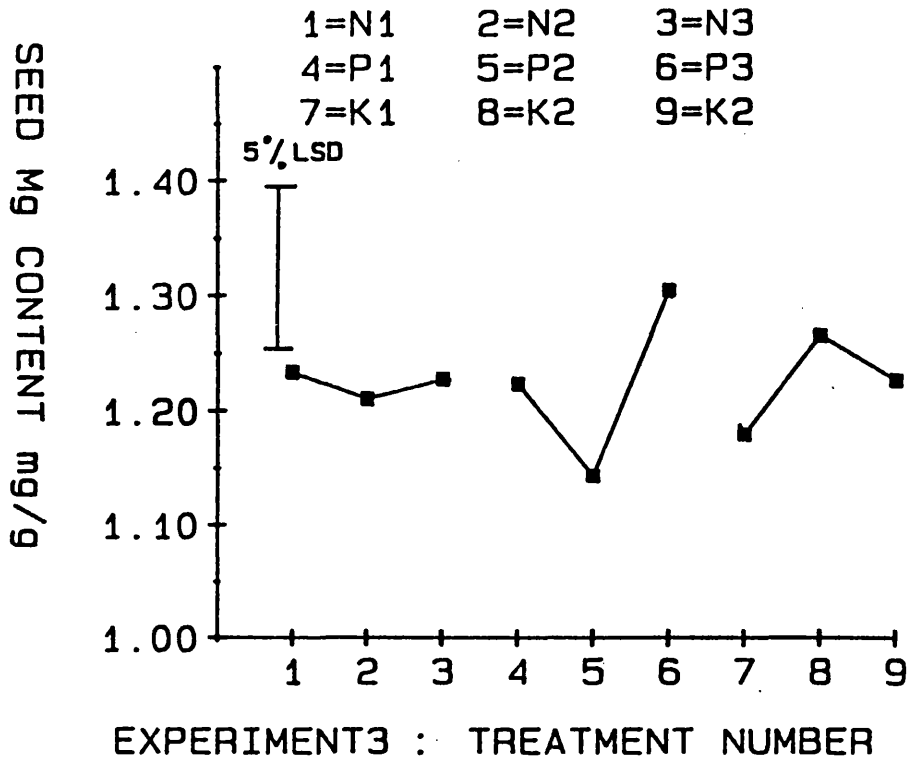

Figure 87. The main effect of N, P and K mineral nutrition levels on seeds' total magnesium content.

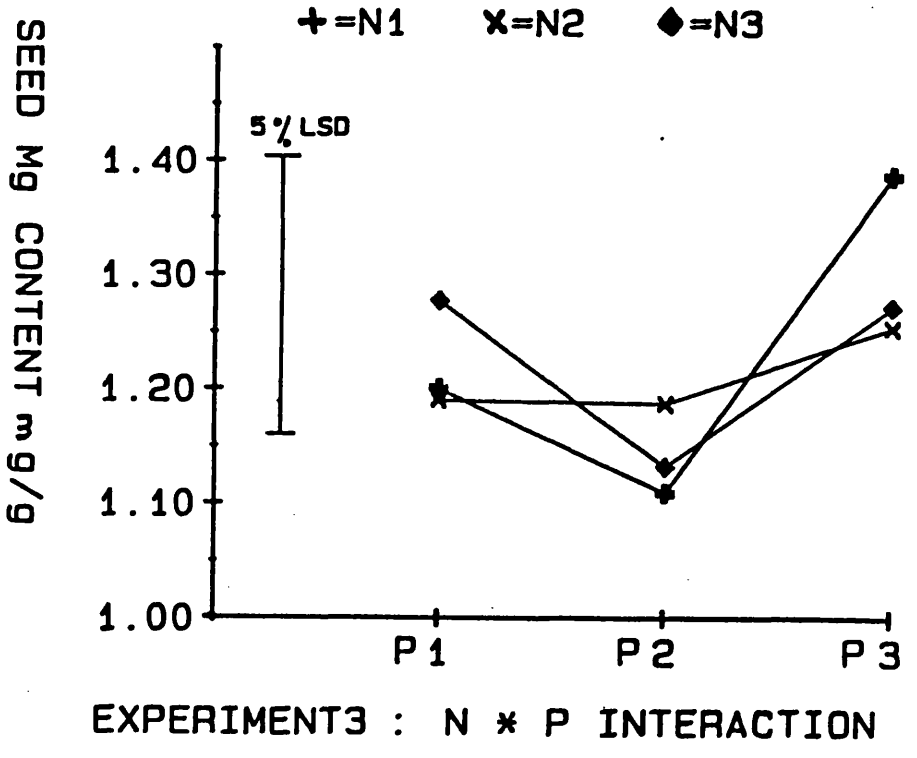

Figure 88. The effect of N and P interaction on seeds' total magnesium content.

From the analysis of variance presented in Table 47, it can be seen that N, P, K and their interactions had no significant effect on seed magnesium content in this experiment.

Figure 87 shows the main effect of N, P and K nutrition levels on seeds' magnesium content.

Figure 88 shows the effect of N and P interaction on seeds' total magnesium content.

4.3.4.4 Experiment 4: Total Seed Magnesium Content

The total seed magnesium content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N, P and K mineral nutrition levels on seed Mg content and to attempt to establish a relationship between seed yield and quality.

Total nutrient levels (mg per plant)	Mg(mg per g)	Total nutrient levels (mg per plant)	Mg(mg per g)
N_1 = 0	1.56	K_1 = 0	1.61
N_2 = 100	1.62	K_2 = 50	1.64
N_3 = 500	1.66	K_3 = 250	1.60
N_4 = 1000	1.58	K_4 = 500	1.57

Significance levels:

N: 5.0% K: N.S., and their interaction Nx K: N.S.

5% LSD = 0.06

Table 48. The effect of N and K nutrition levels on total seed magnesium content in Experiment 4.

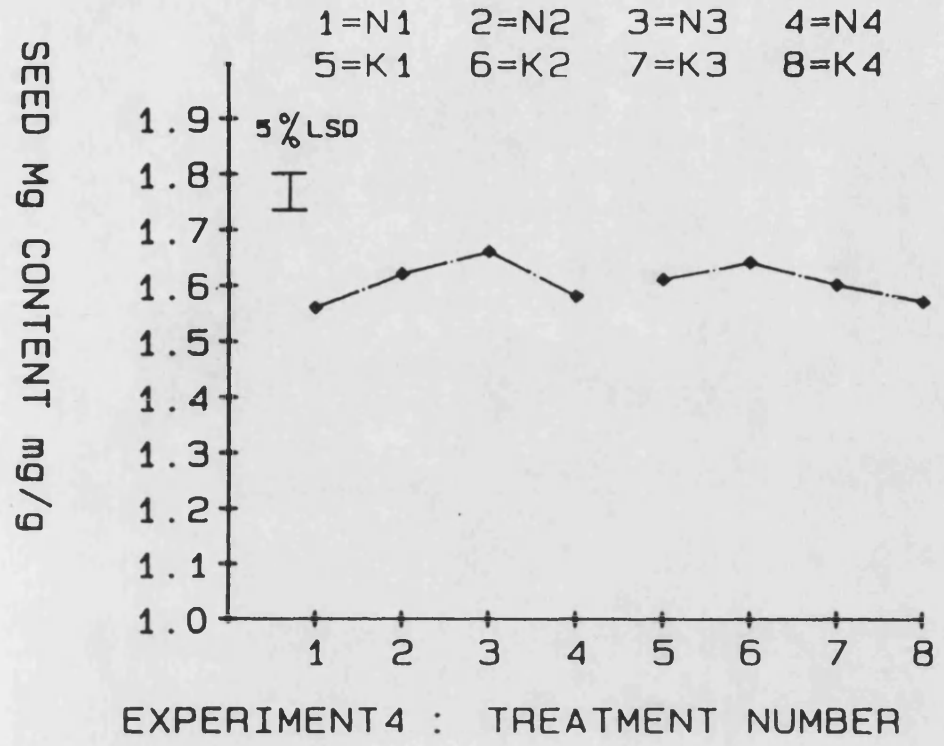

Figure 89. The main effect of N and K mineral nutrition levels on seeds' total magnesium content.

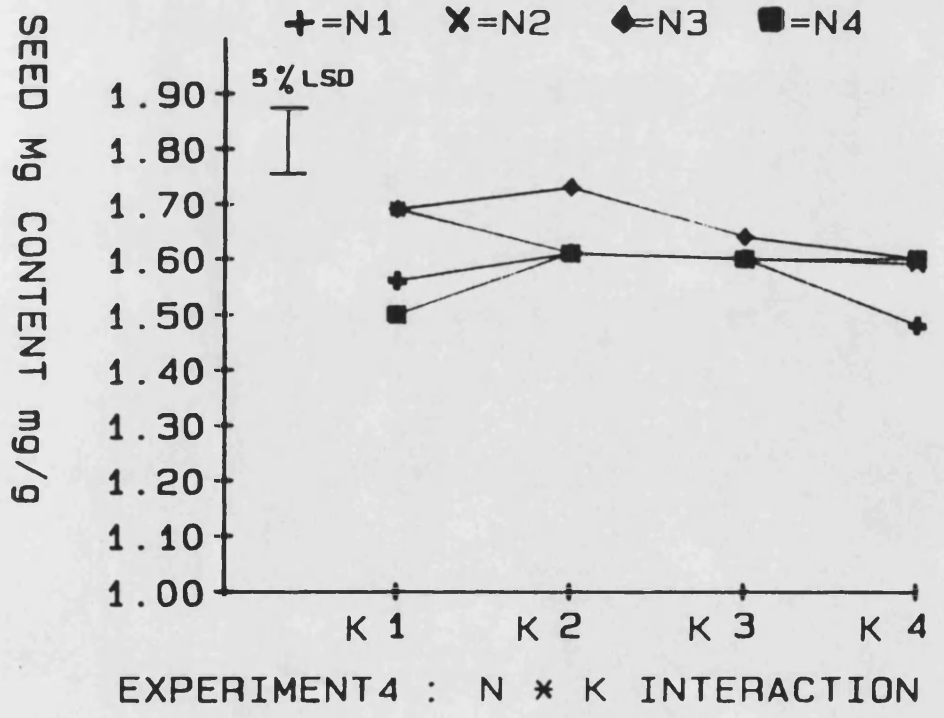

Figure 90. The effect of N K interaction on seeds' total magnesium content.

From the analysis of variance presented in Table 48, it can be seen that only levels of N significantly affected the total seed magnesium content at just the 5.0% level. Neither levels of K nor their N x K interaction significantly affected the seeds' magnesium content.

As shown in Figure 89, the seed magnesium content increased with increasing levels of N up to the N_3 level and then significantly decreased at the fourth level of N in the order of $N_1 < N_2 < N_3 > N_4$, in this experiment.

Figure 90 shows the effect of NK interaction on seeds' total Mg content.

4.3.5.1 Experiment 1: Total Seed Manganese Content

The total seed manganese content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N, P and K mineral nutrition levels on seed Mn content and to attempt to establish a relationship between seed yield and quality.

Total nutrient levels (mg per plant)	Mn (µg per g)	Total Nutrient levels (mg per plant)	Mn (µg per g)	Total nutrient levels (mg per plant)	Mn (µg per g)
N_1 = 100	17.63	P_1 = 50	20.12	K_1 = 40	20.85
N_2 = 150	17.79	P_2 = 70	20.68	K_2 = 60	19.81
N_3 = 300	19.10	P_3 = 140	18.87	K_3 = 120	18.58
N_4 = 500	23.05	P_4 =210	17.90	K_4 = 180	18.34

Significance levels:

N: 0.1% N x P: 1.0%

P: 0.1% N x K: N.S. N x P x K: N.S.

K: 1.0% P x K: N.S.

L.S.D. (N,P,K) = 1.32 (NxP,PxK,NxK) = 2.63 (N x P x K) = 5.26

Table 49. The effect of N, P and K mineral nutrition levels on total seed manganese content in Experiment 1.

From the analysis of variance presented in Table 49, it can be seen that the levels of N, P and K and the interaction NP significantly affected the total seed Mn content at the 0.1%, 0.1%, 1.0% and 1.0% levels respectively.

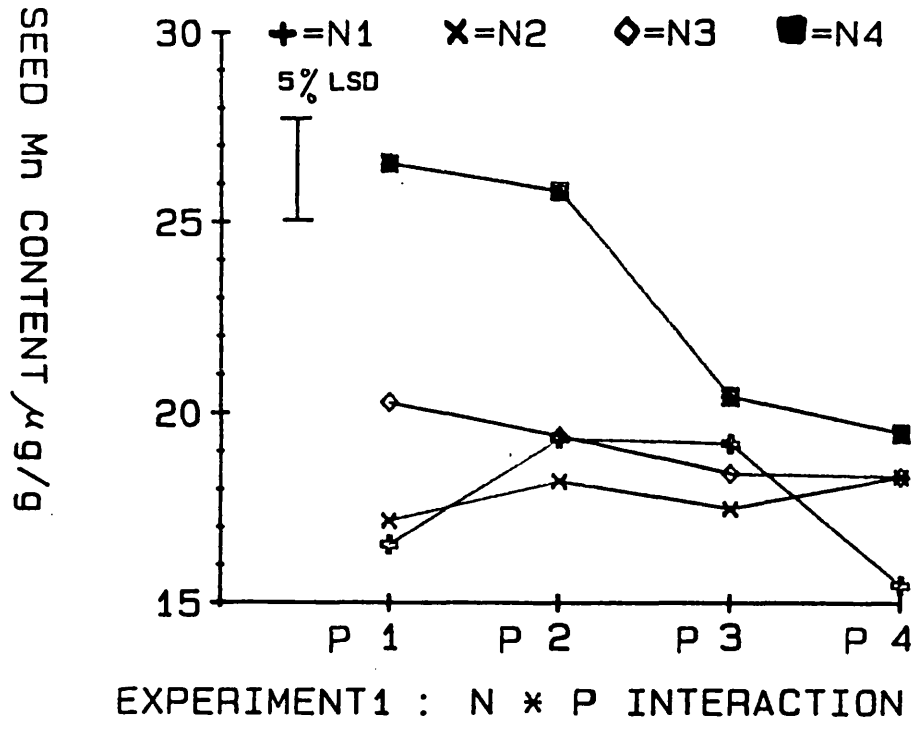

Figure 91. The effect of N and P interaction levels on seeds' total manganese content.

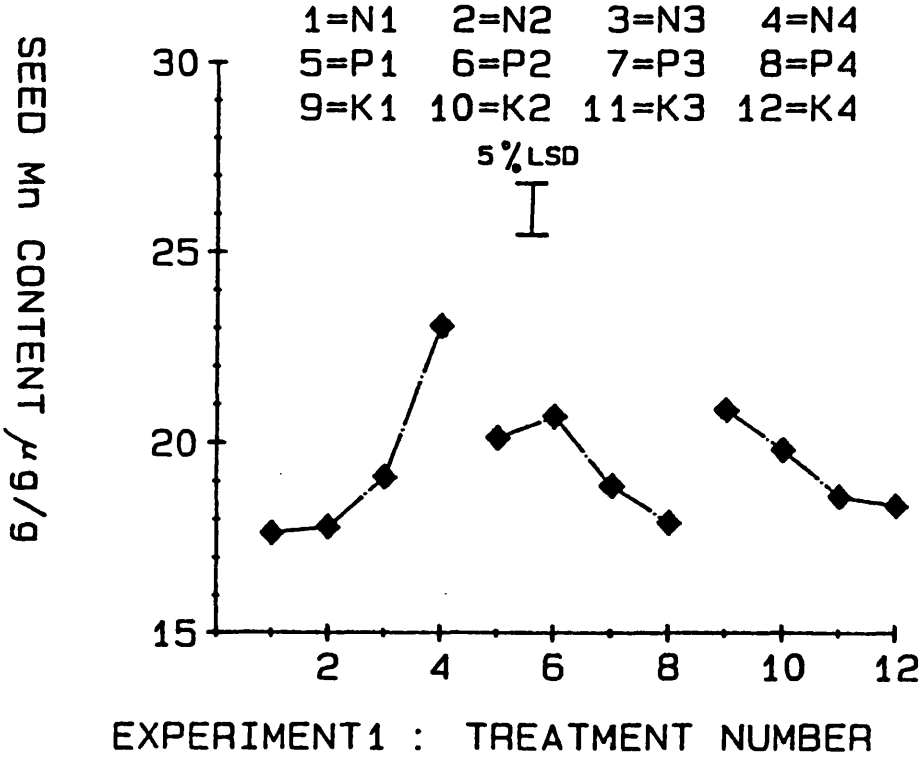

Figure 92. The main effect of N, P and K mineral nutrition levels on seeds' total manganese content.

As shown in Figure 92, the seed Mn content increased with increasing levels of N and decreased with increasing levels of P and K in this experiment and in the orders of $N_4 > N_3 > N_2 > N_1$, $P_2 > P_1 > P_3 > P_4$, and $K_1 > K_2 > K_3 > K_4$.

Figure 91 shows the effect of N and P interaction on seed total manganese content.

4.3.5.2 Experiment 2: Total Seed Manganese Content

The total seed manganese content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N and P mineral nutrition levels on seed Mg content and to attempt to establish a relationship between seed yield and quality.

Total nutrient levels (mg per plant)	Mn (µg per g)	Total nutrient levels (mg per plant)	Mn(µg per g)
N_1 = 100	28.65	P_1 = 25	24.31
N_2 = 1000	21.20	P_2 = 250	23.14
		P_3 = 500	24.64
		P_4 = 1000	27.61

Significance levels:

N:	0.1%	P: 0.1%	N x P: 0.1%
5% LSD	N: 0.99	P: 1.41	N x P: 1.99

Table 50. The effect of N and P nutrition levels on the total seed manganese content in Experiment 2.

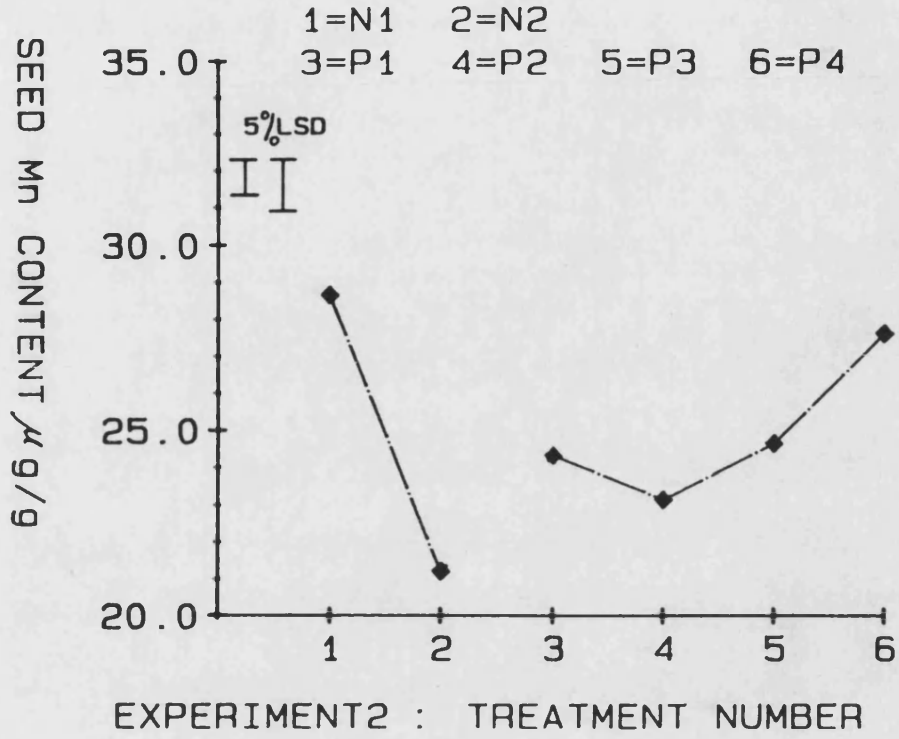

Figure 93. The main effect of N and P mineral nutrition levels on seeds' total manganese content.

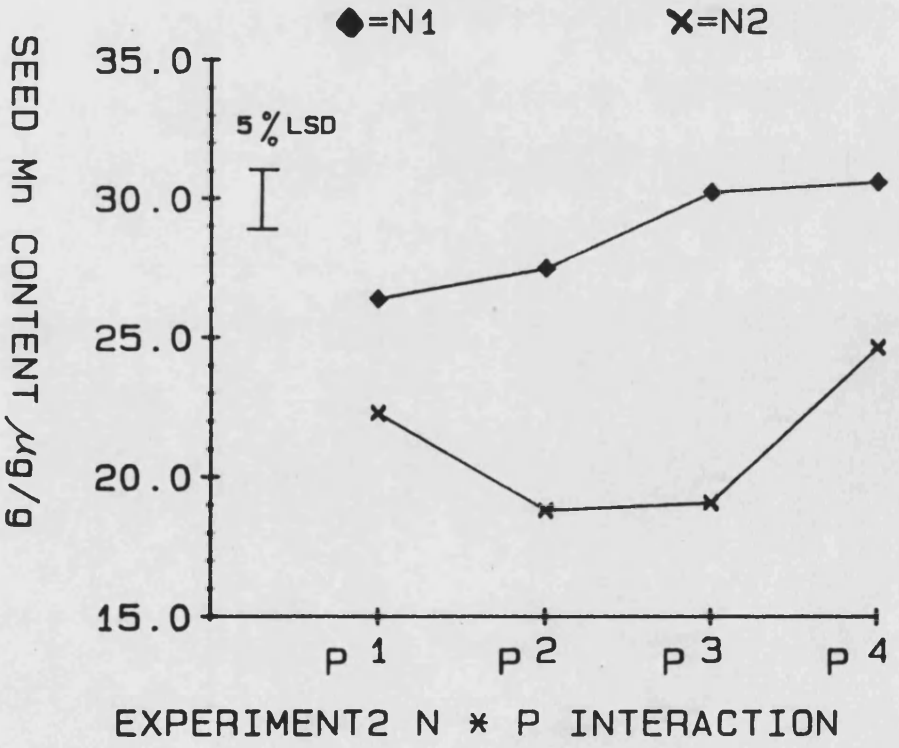

Figure 94. The effect of N and P interaction on seeds' total manganese content.

From the analysis of variance presented in Table 50, it can be seen that the levels of N, P and their interaction NP significantly affected the total seed Mn content at the high significance level of 0.1% in this experiment.

As shown in Figure 93, seed Mn content decreased with increasing levels of N and increased with increasing levels of P after an initial derease from P_1 to P_2 as shown in the following orders: $N_1 > N_2$ and $P_4 > P_3 > P_1 > P_2$.

Figure 94 shows the effect of N and P interaction on seeds' total Mn content. The highest Mn content was achieved by the combination N_1P_4 (30.57 µg per g) and the lowest by N_2P_2 (18.80 µg per g).

4.3.5.3 Experiment 3: Total Seed Manganese Content

The total seed manganese content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N, P and K mineral nutrition levels on seed Mg content and to attempt to establish a relationship between seed yield and quality. From the analysis of variance presented in Table 51, it can be seen that only the interaction of the P and K levels significantly affected the total seed manganese content in this experiment.

Figure 95 shows the main effect of N, P and K nutrition levels on seeds' manganese content.

Figure 96 shows the effect of P and K interaction on seeds' manganese content. The highest seed manganese content was achieved by the combination P_2K_1 (20.22 µg per g) and the lowest by P_2K_2 (16.47 µg per g).

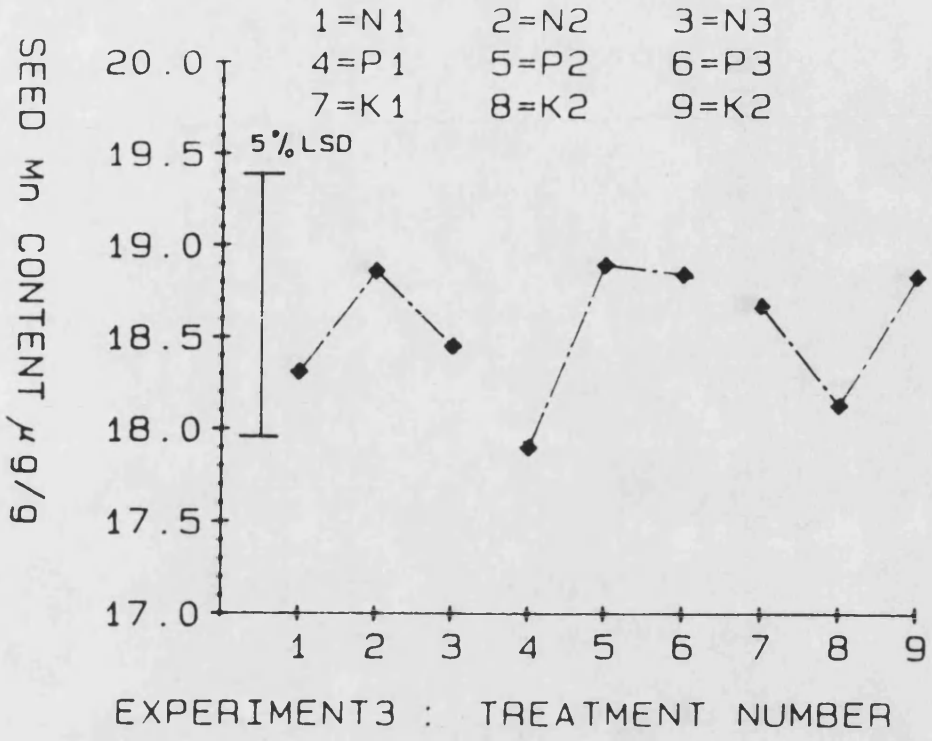

Figure 95. The main effect of N, P and K mineral nutrition levels on seeds' total manganese content.

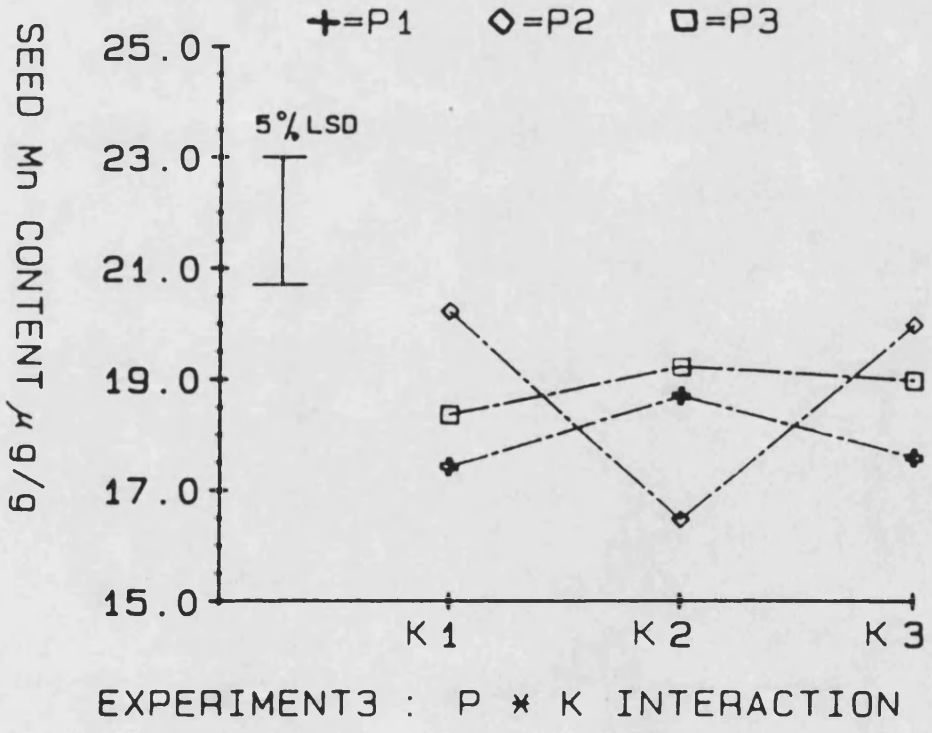

Figure 96. The effect of P and K interaction on seeds' total manganese content.

Total nutrient levels (kg per ha)	Mn (µg per g)	Total nutrient levels (kg per ha)	Mn (µg per (g)	Total nutrient levels (kg per ha)	Mn (µg per (g)
$N_1 = 0$	18.31	$P_1 = 0$	17.90	$K_1 = 0$	18.67
$N_2 = 25$	18.36	$P_2 = 50$	18.89	$K_2 = 25$	18.13
$N_3 = 75$	18.45	$P_3 = 150$	18.84	$K_3 = 75$	18.83

Significance levels:

N: N.S. N x P: N.S.

P: N.S. N x K: N.S. N x P x K: N.S.

K: N.S. P x K: 5.0%

L.S.D. 5%
(N,P,K) = 1.40 (NxP,PxK,NxK) = 2.43 (N x P x K) = 4.20

Table 51. The effect of N, P and K mineral nutrition levels on total seed manganese content in Experiment 3.

4.3.5.4 Experiment 4: Total Seed Manganese Content

The total seed manganese content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N and K mineral nutrition levels on seed Mg content and to attempt to establish a relationship between seed yield and quality. From the analysis of variance presented in Table 52, it can be seen that levels of N and K significantly affected the total seed manganese content at the 0.1% level. The N and K interaction had no significant effect.

As shown in Figure 97, the total seed manganese content increased with increasing levels of N in the order of $N_1 < N_2 < N_3 < N_4$,

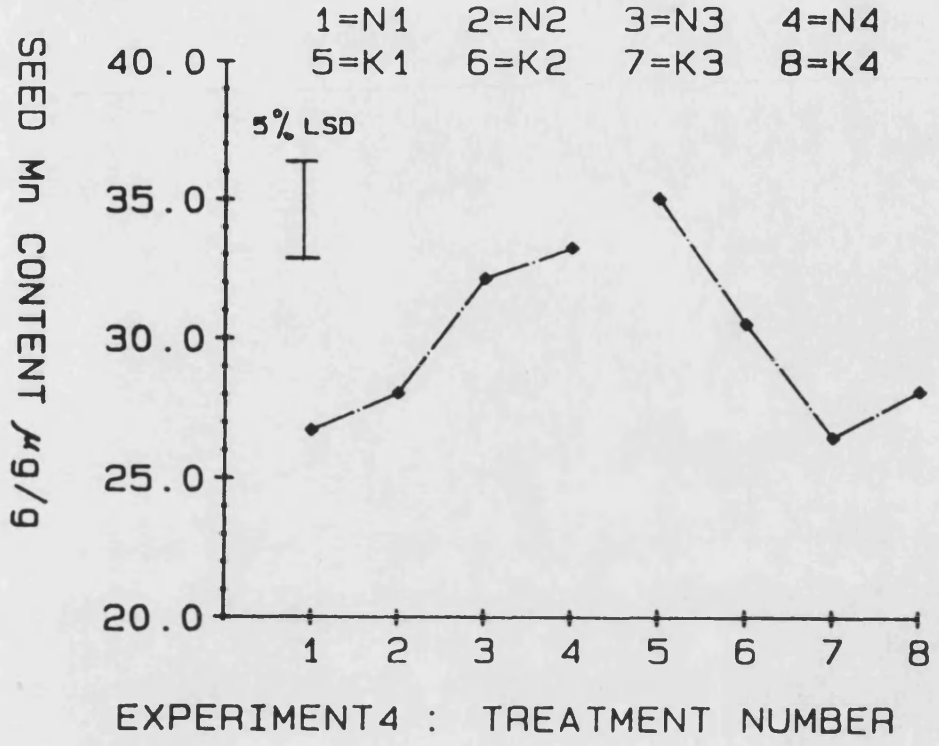

Figure 97. The main effect of N and K mineral nutrition levels on seeds' total manganese content.

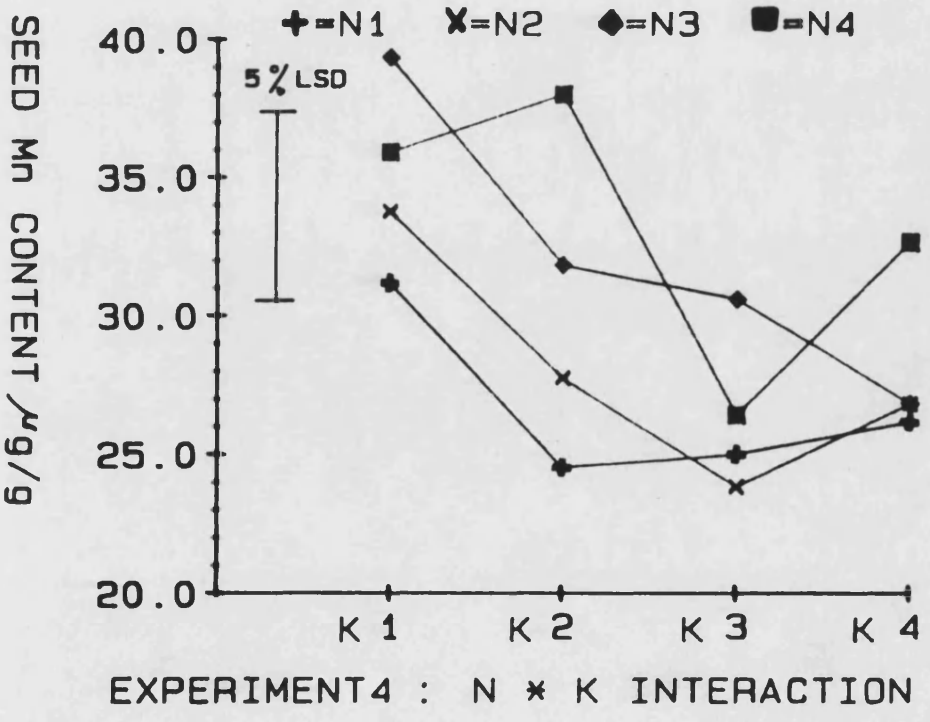

Figure 98. The effect of NK interaction on seeds' total manganese content.

Total nutrient levels (mg per plant)	Mn (µg per g)	Total nutrient levels (mg per plant)	Mn(µg per g)
N_1 = 0	26.71	K_1 = 0	35.04
N_2 = 100	28.04	K_2 = 50	30.53
N_3 = 500	32.15	K_3 = 250	26.46
N_4 = 1000	33.25	K_4 = 500	28.13

Significance levels:

N: 0.1% K: 0.1%, and their interaction Nx K: N.S.

5% LSD = 3.43

Table 52. The effect of N and K nutrition levels on total seed manganese content in Experiment 4.

whereas decreased with increasing levels of K up to the third level and began to increase with the fourth level of K, in the order of $K_1 > K_2 > K_3 < K_4$, in this experiment.

Figure 98 shows the effect of NK interaction on seeds' total manganese content.

4.3.6.1 Experiment 1: Total Seed Iron Content

The total seed iron content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N, P and K mineral nutrition levels on seed Fe content and to attempt to establish a relationship between seed yield and quality.

Total nutrient levels (mg per plant)	Fe (µg per g)	Total Nutrient levels (mg per plant)	Fe (µg per g)	Total nutrient levels (mg per plant)	Fe (µg per g)
N_1 = 100	86.1	P_1 = 50	91.1	K_1 = 40	89.9
N_2 = 150	80.0	P_2 = 70	80.1	K_2 = 60	79.4
N_3 = 300	77.3	P_3 = 140	75.2	K_3 = 120	74.4
N_4 = 500	78.3	P_4 =210	75.2	K_4 = 180	74.9

Significance levels:

N: 0.1% N x P: 0.1%

P: 0.1% N x K: 0.1% N x P x K: 1.0%

K: 0.1% P x K: 5.0%

L.S.D. (N,P,K) = 3.73 (NxP,PxK,NxK) = 7.46 (N x P x K) = 14.91

Table 53. The effect of N, P and K mineral nutrition levels on total seed iron content in Experiment 1.

From the analysis of variance presented in Table 53, it can be seen that the levels of N, P and K and the interactions NP and NK significantly affected the seed Fe content at the 0.1% significance level and that the interactions PK and NPK at the 5.0% and 1.0% significance level respectively.

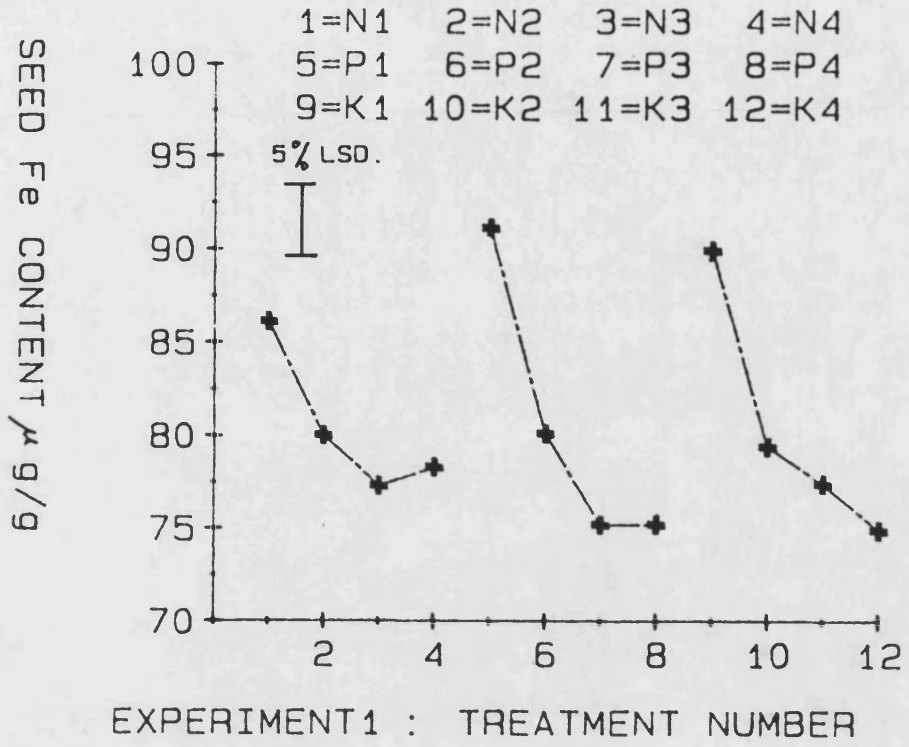

Figure 99. The main effect of N, P and K mineral nutrition levels on seeds' total iron content.

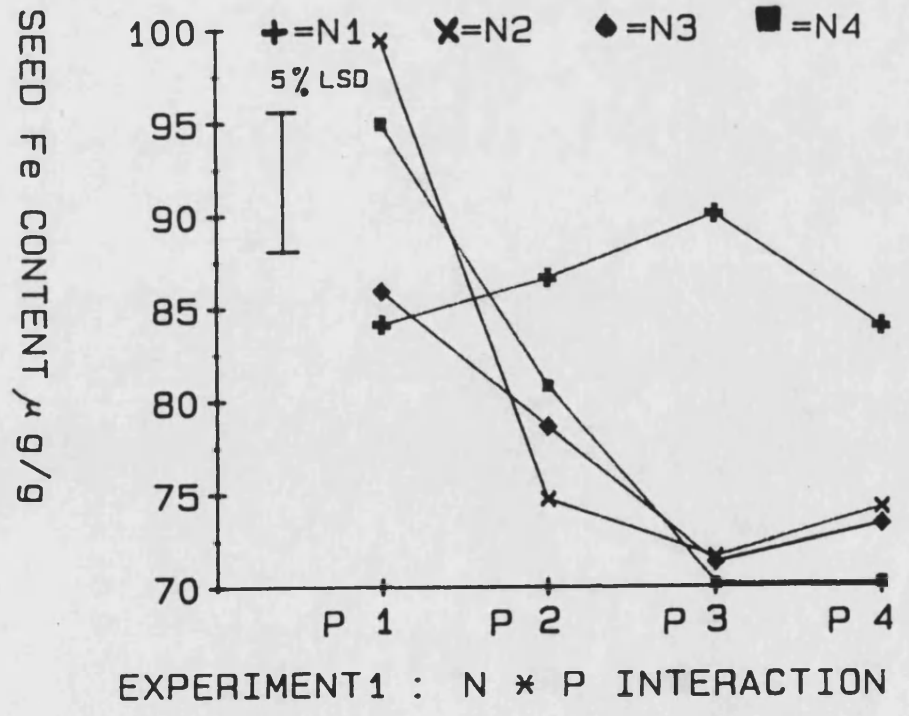

Figure 100. The effect of N and P interaction on seeds' total iron content.

As shown in Figure 99 the seeds' total Fe content decreased with increasing levels of N, P and K in this experiment in the orders of $N_1 > N_2 > N_4 > N_3$, $P_1 > P_2 > P_3 = P_4$ and $K_1 > K_2 > K_3 > K_4$.

Figure 100 shows the effect of N and P interaction on seeds' total iron content.

4.3.6.2 Experiment 2: Total Seed Iron Content

The total seed iron content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N and P mineral nutrition levels on seed Fe content and to attempt to establish a relationship between seed yield and quality.

Total nutrient levels (mg per plant)	Fe(µg per g)	Total nutrient levels (mg per plant)	Fe(µg per g)
N_1 = 100	123.9	P_1 = 25	133.7
N_2 = 1000	139.5	P_2 = 250	126.3
		P_3 = 500	139.6
		P_4 = 1000	127.1

Significance levels:

N:	0.1%	P: N.S.	N x P: N.S.
5% LSD	N: 7.57	P: 10.71	N x P:15.14

Table 54. The effect of N and P nutrition levels on the total seed iron content in Experiment 2.

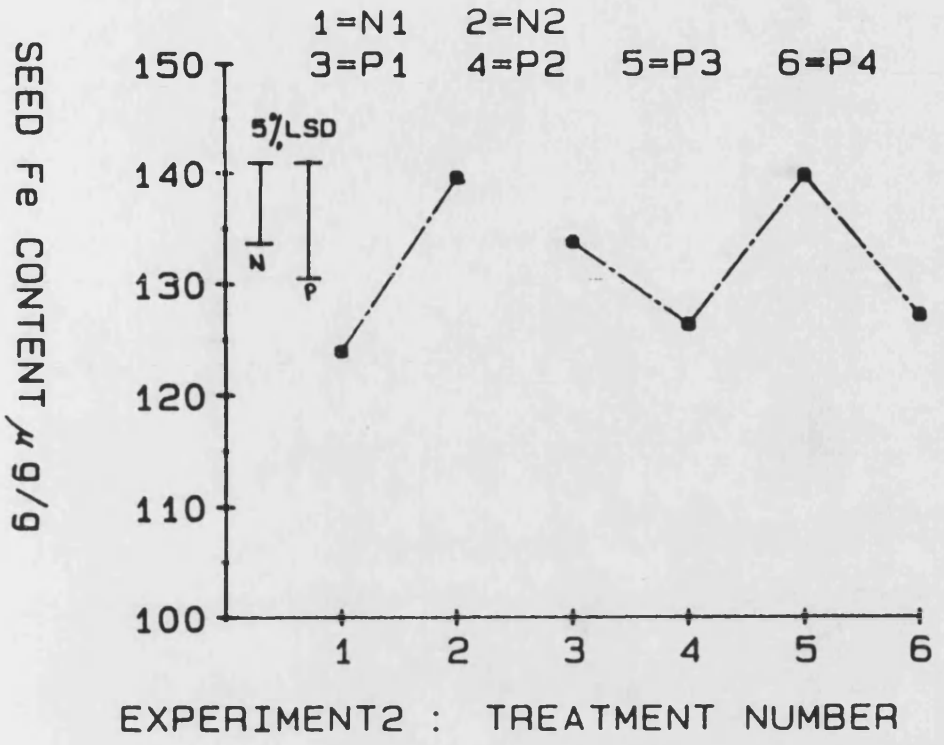

Figure 1C1. The main effect of N and P mineral nutrition levels on seeds' total iron content.

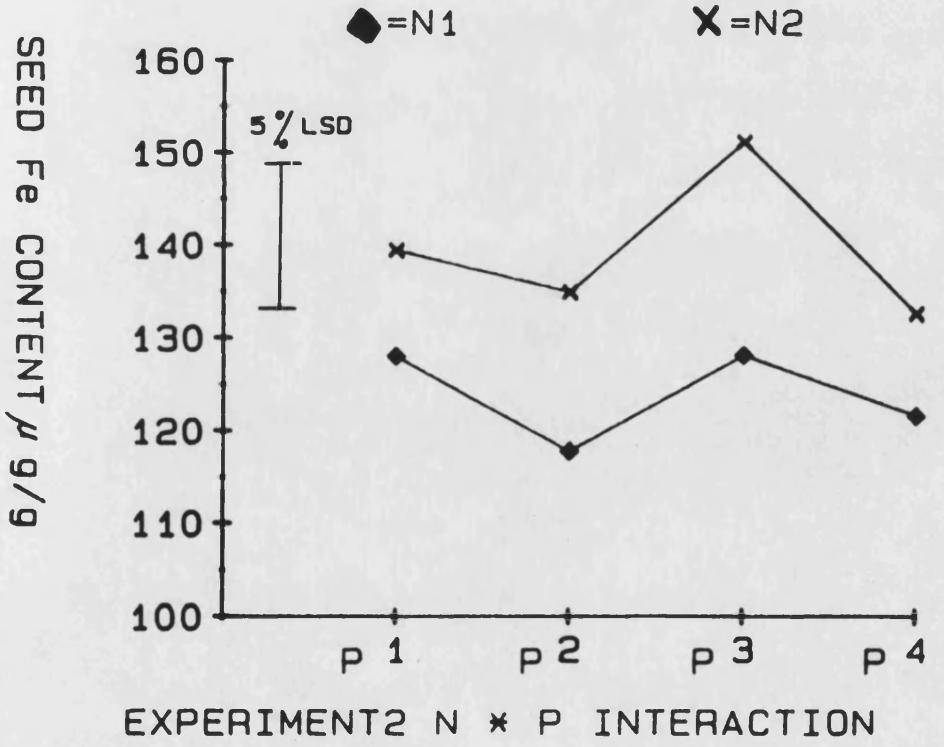

Figure 1C2. The effect of N and P interaction on seeds' total iron content.

From the analysis of variance presented in Table 54, it can be seen that only the levels of N significantly affected the seed Fe content at the 0.1% significance level in this experiment.

As shown in Figure 101, the total seed iron content increased with increasing levels of N and that the levels of P had the following effect, but not significantly $P_3 > P_1 > P_4 > P_2$.

Figure 102 shows the effect of N and P interaction on seeds' total iron content.

4.3.6.3 Experiment 3: Total Seed Iron Content

The total seed iron content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the

Total nutrient levels (kg per ha)	Fe (µg per g)	Total nutrient levels (kg per ha)	Fe (µg per (g)	Total nutrient levels (kg per ha)	Fe (µg per (g)
$N_1 = 0$	84.9	$P_1 = 0$	82.8	$K_1 = 0$	81.6
$N_2 = 25$	83.3	$P_2 = 50$	83.3	$K_2 = 25$	85.1
$N_3 = 75$	85.8	$P_3 = 150$	87.9	$K_3 = 75$	87.4

Significance levels:

N: N.S. N x P: N.S.

P: N.S. N x K: N.S. N x P x K: N.S.

K: N.S. P x K: N.S.

L.S.D. 5%
(N,P,K) = 8.26 (NxP,PxK,NxK) = 14.31 (N x P x K) = 27.78

Table 55. The effect of N, P and K mineral nutrition levels on total seed iron content in Experiment 3.

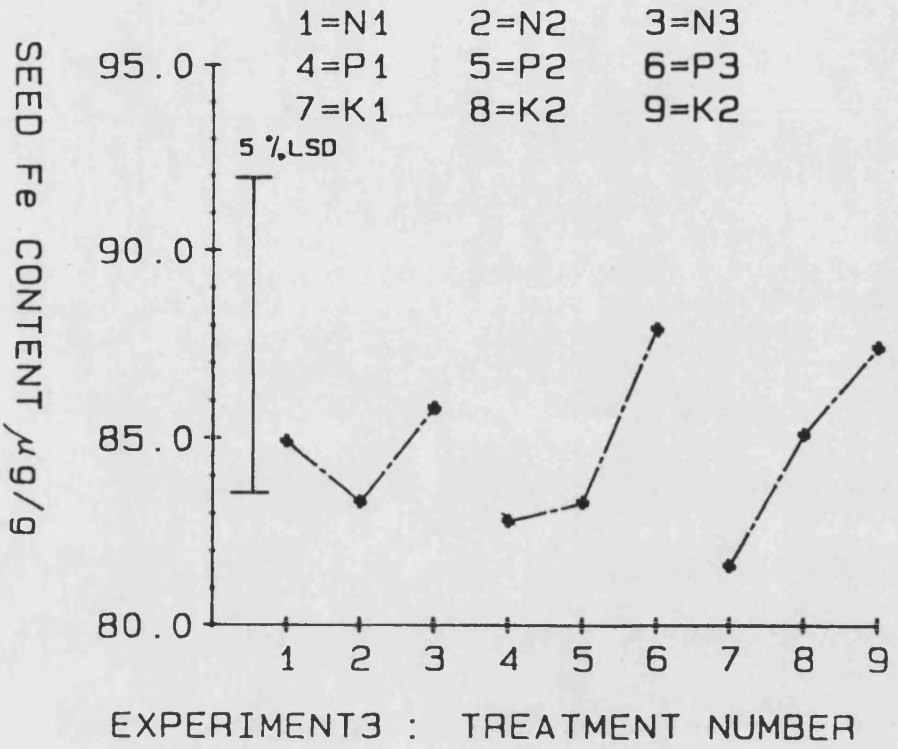

Figure 103. The main effect of N, P and K mineral nutrition levels on seeds' total iron content.

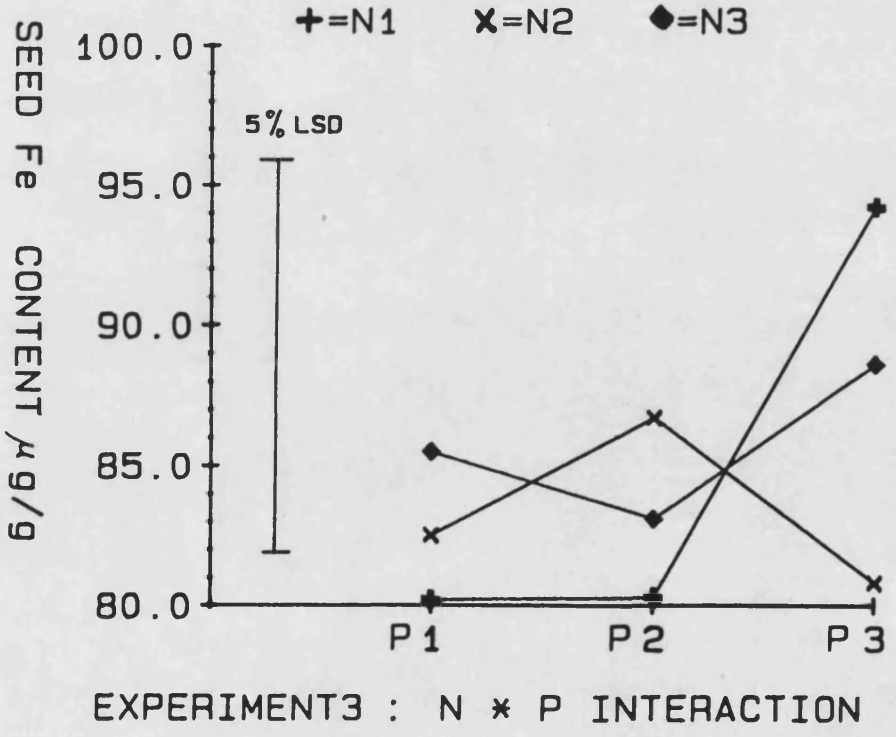

Figure 104. The effect of N and P interaction on seeds' total iron content.

effect of N, P and K mineral nutrition levels on seed Fe content and to attempt to establish a relationship between seed yield and quality. From the analysis of variance presented in Table 55 it can be seen that neither N, P and K or their interactions had a significant effect on seed iron content in this experiment.

Figure 103 shows the main effect of N, P and K nutrition levels on seeds' total iron content.

Figure 104 shows the effect of N and P interaction on seeds' total iron content.

4.3.6.4 Experiment 4: Total Seed Iron Content

The total seed iron content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N and K mineral nutrition levels on seed Fe content and to attempt to establish a relationship between seed yield and quality.

Total nutrient levels (mg per plant)	Fe (µg per g)	Total nutrient levels (mg per plant)	Fe(µg per g)
N_1 = 0	121.7	K_1 = 0	133.8
N_2 = 100	121.5	K_2 = 50	127.3
N_3 = 500	136.9	K_3 = 250	121.5
N_4 = 1000	123.3	K_4 = 500	120.8

Significance levels:

N: N.S. K: N.S., and their interaction Nx K: N.S.

5% LSD = 13.67

Table 56. The effect of N and K nutrition levels on total seed iron content in Experiment 4.

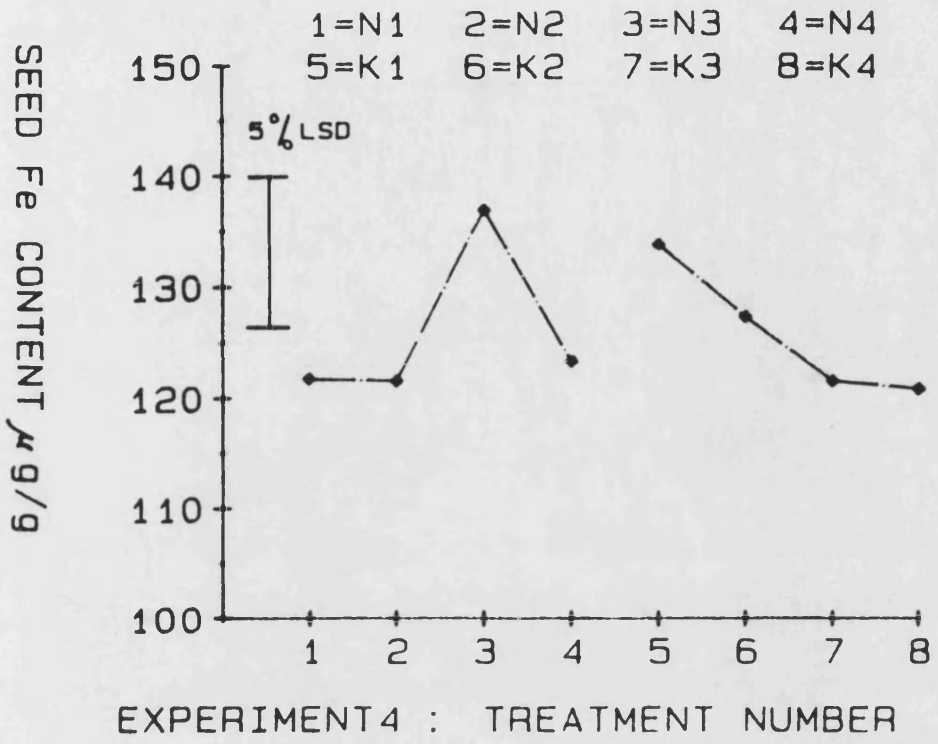

Figure 105. The main effect of N and K mineral nutrition levels on seeds' Total iron content.

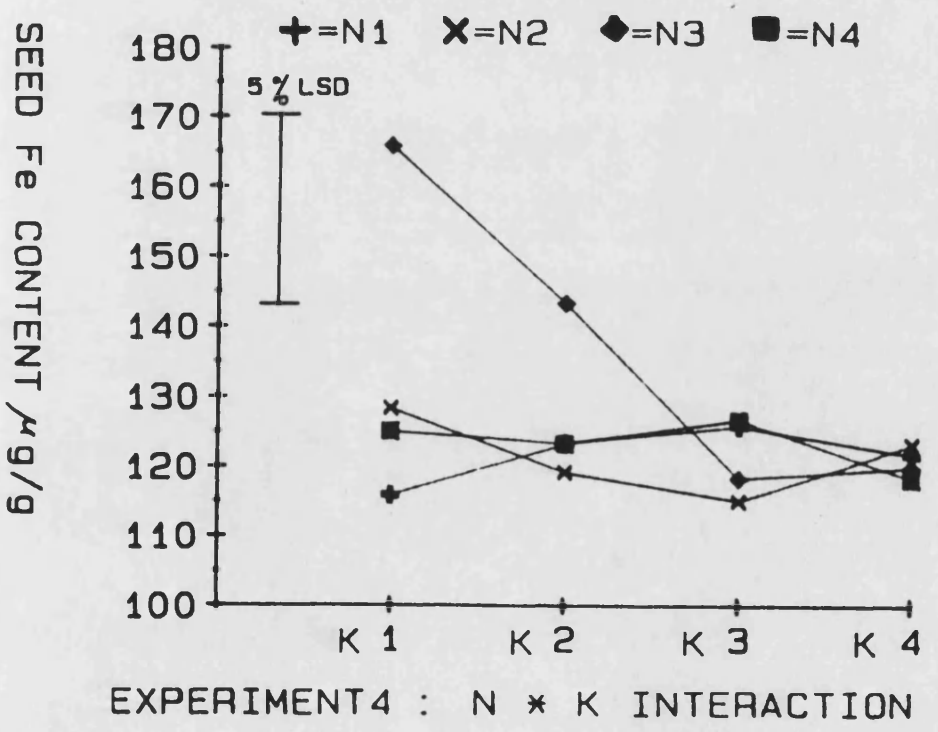

Figure 106. The effect of n K interaction on seeds' total iron content.

From the analysis of variance presented in Table 56 it can be seen that neither levels of N and K nor their interaction N x K had a significant effect on total seed iron content.

Figure 105 shows the main effectof N and K levels on seeds' total iron content in this experiment.

Figure 106 shows the effect of N and K interaction on seeds' total Fe content.

4.3.7.1 Experiment 1: Total Seed Copper Content

The total seed copper content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N, P and K mineral nutrition levels on seed total copper content and to attempt to establish a relationship between seed yield and quality.

Total nutrient levels (mg per plant)	Cu (µg per g)	Total Nutrient levels (mg per plant)	Cu (µg per g)	Total nutrient levels (mg per plant)	Cu (µg per g)
N_1 = 100	0.921	P_1 = 50	0.799	K_1 = 40	0.731
N_2 = 150	0.875	P_2 = 70	0.994	K_2 = 60	0.878
N_3 = 300	0.817	P_3 = 140	0.804	K_3 = 120	0.868
N_4 = 500	0.770	P_4 =210	0.792	K_4 = 180	0.913

Significance levels:

N: 0.1%	N x P: 0.1%	
P: 0.1%	N x K: 0.1%	N x P x K: 0.1%
K: 0.1%	P x K: 0.1%	

L.S.D. (N,P,K) = 0.042 (NxP,PxK,NxK) = 0.085 (N x P x K) = 0.170

Table 57. The effect of N, P and K mineral nutrition levels on total seed copper content in Experiment 1.

From the analysis of variance presented in Table 57 it can be seen that the levels of N, P and K and their interaction NP, NK, PK and NPK signficantly affected the total seed copper content at 0.1% significance level.

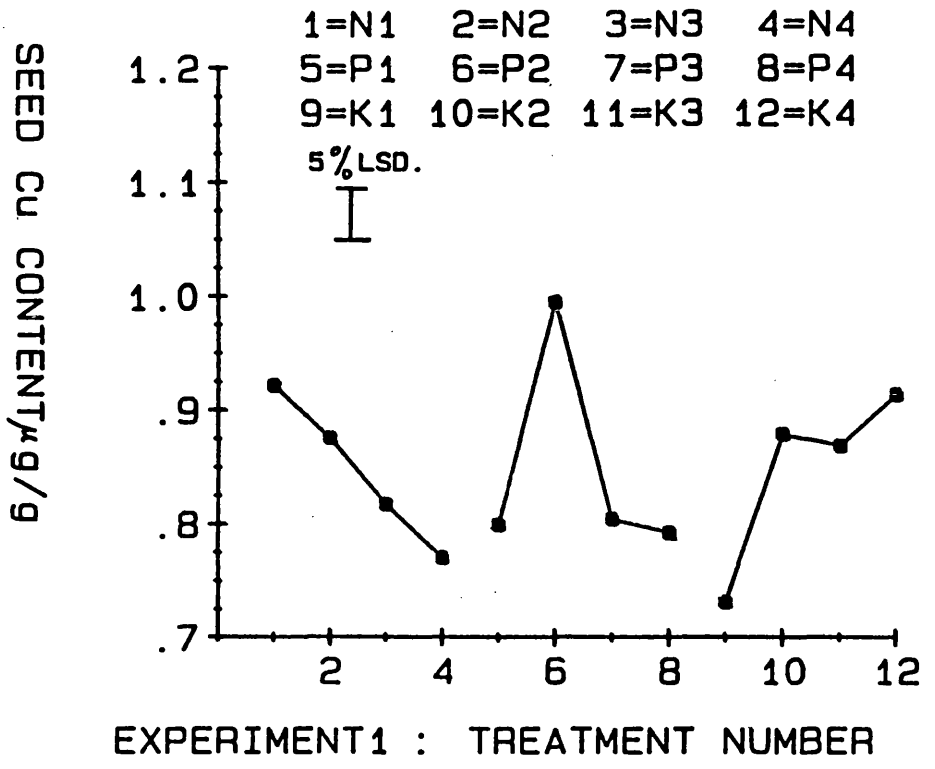

Figure 107. The main effect of N, P and K mineral nutrition levels on seeds' total copper content.

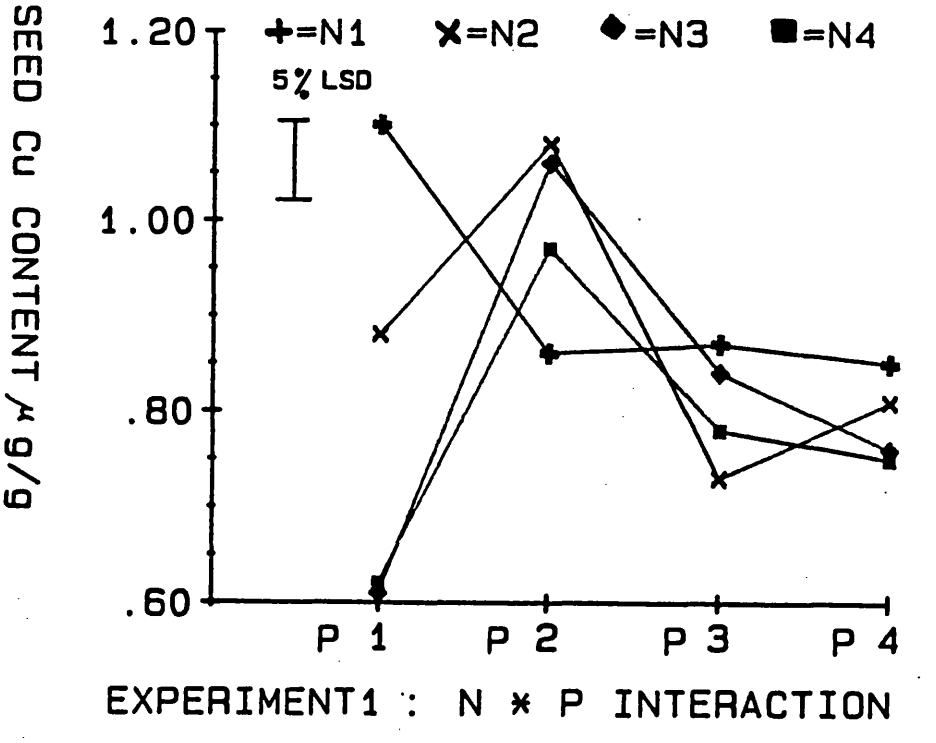

Figure 108. The effect of N and P interaction on seeds' total copper content.

As shown in Figure 107, the seeds' total Cu content decreased with increasing levels of N and it also decreased with increasing levels of P after an initial rise from P_1 to P_2 and it increased with increasing levels of K in this experiment and in the orders of $N_1 > N_2 > N_3 > N_4$, $P_2 > P_3 > P_1 \simeq P_4$ and $K_4 > K_2 \simeq K_3 > K_1$.

Figure 108 shows the effect of N and P interaction on seeds' total copper content.

4.3.7.2 Experiment 2: Total Seed Copper Content

The total seed copper content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N and P mineral nutrition levels on seed Mg content and to attempt to establish a relationship between seed yield and quality.

Total nutrient levels (mg per plant)	Cu(µg per g)	Total nutrient levels (mg per plant)	Cu(µg per g)
N_1 = 100	5.63	P_1 = 25	5.39
N_2 = 1000	4.75	P_2 = 250	4.40
		P_3 = 500	5.00
		P_4 = 1000	5.97

Significance levels:

N:	N.S.	P: N.S.	N x P: N.S.
5% LSD	N: 0.97	P: 1.37	N x P: 1.93

Table 58. The effect of N and P nutrition levels on the total seed copper content in Experiment 2.

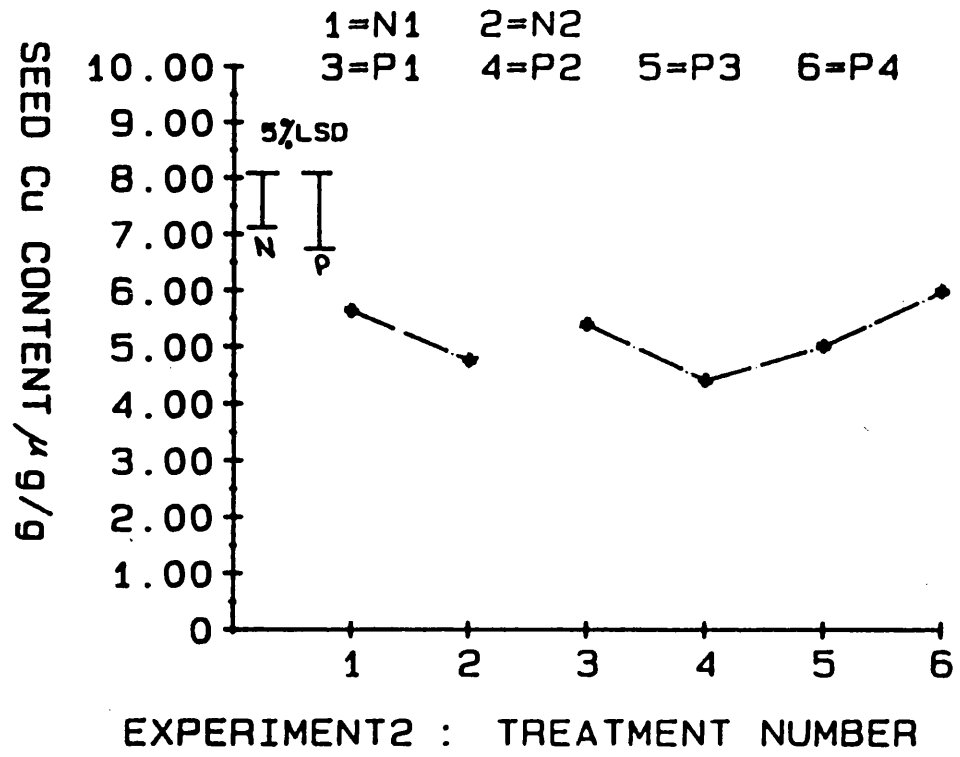

Figure 109. The main effect of N and P mineral nutrition levels on seeds' total copper content.

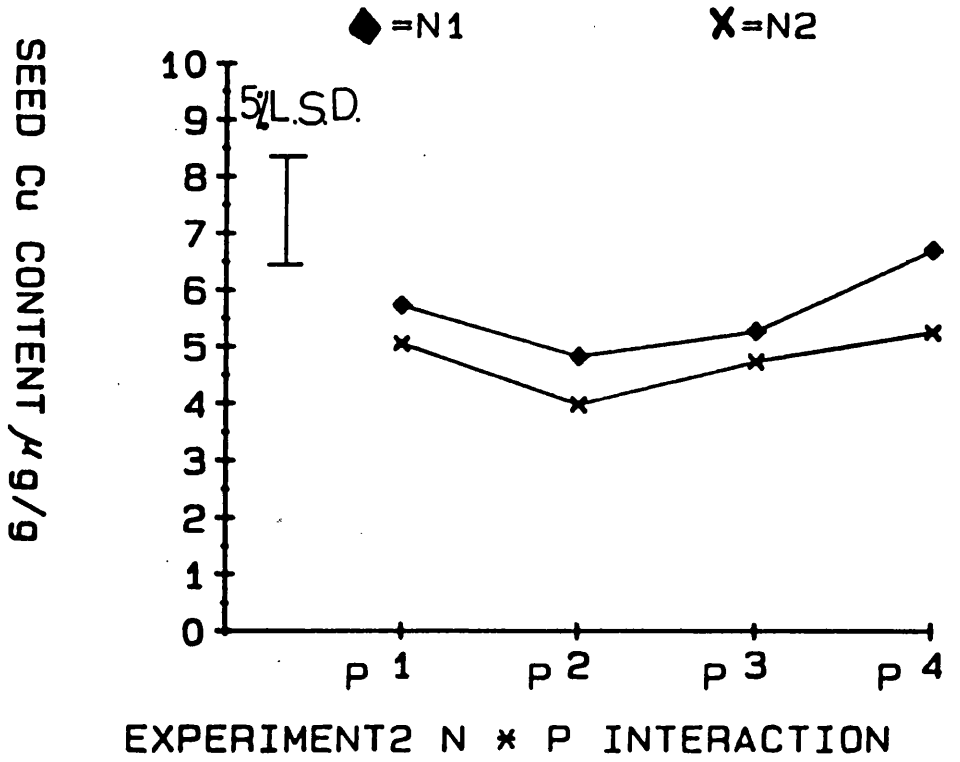

Figure 110. The effect of N and P interaction on seeds' total copper content.

From the analysis of variance presented in Table 58, it can be seen that none of the levels of N and P,or their interaction had any significant effect on total seed copper content.

As shown in Figure 109, increasing levels of N decreased seed Cu content and that P levels increased seed Cu content but not significantly in this experiment.

Figure 110 shows the effect of N and P interaction on seeds' total copper content.

4.3.7.3 Experiment 3: Total Seed Copper Content

The total seed copper content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N, P and K mineral nutrition levels on seed Cu content and to attempt to establish a relationship between seed yield and quality.

Total nutrient levels (kg per ha)	Cu (µg per g)	Total nutrient levels (kg per ha)	Cu (µg per (g)	Total nutrient levels (kg per ha)	Cu (µg per (g)
N_1 = 0	10.72	P_1 = 0	9.59	K_1 = 0	9.57
N_2 = 25	9.57	P_2 = 50	9.76	K_2 = 25	9.71
N_3 = 75	8.82	P_3 = 150	9.76	K_3 = 75	9.87

Significance levels:

N: 0.1% N x P: 5.0%

P: N.S. N x K: N.S. N x P x K: N.S.

K: N.S. P x K: N.S.

L.S.D. 5%
(N,P,K) = 0.424 (NxP,PxK,NxK) = 0.734 (N x P x K) = 1.271

Table 59. The effect of N, P and K mineral nutrition levels on total seed copper content in Experiment 3.

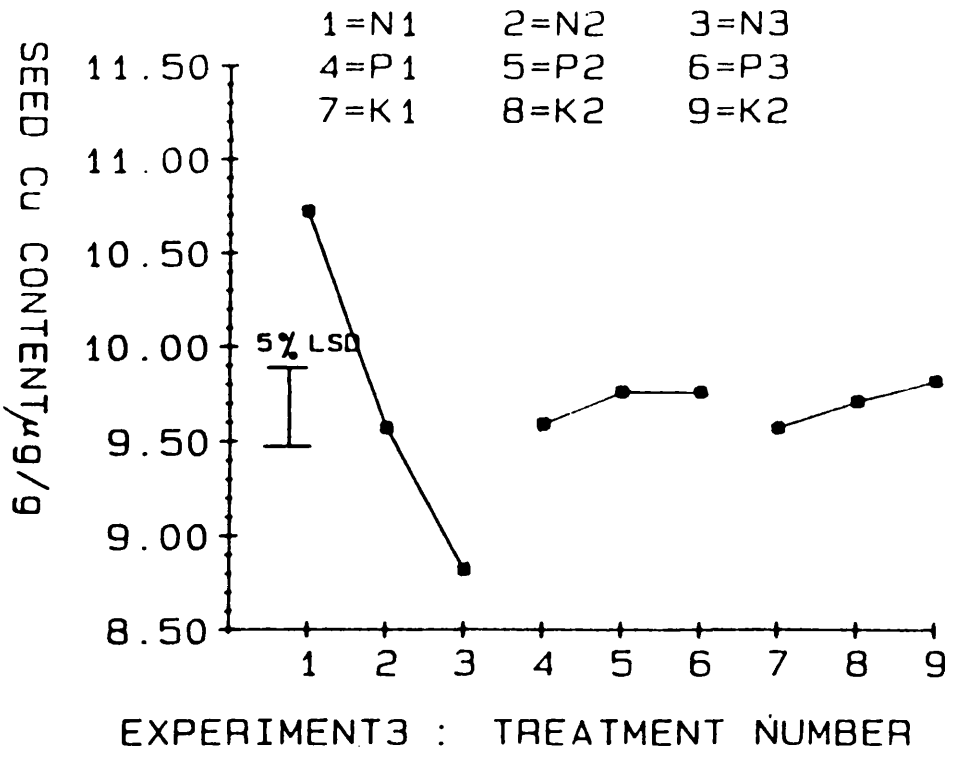

Figure 111. The main effect of N, P and K mineral nutrition levels on seeds' copper content.

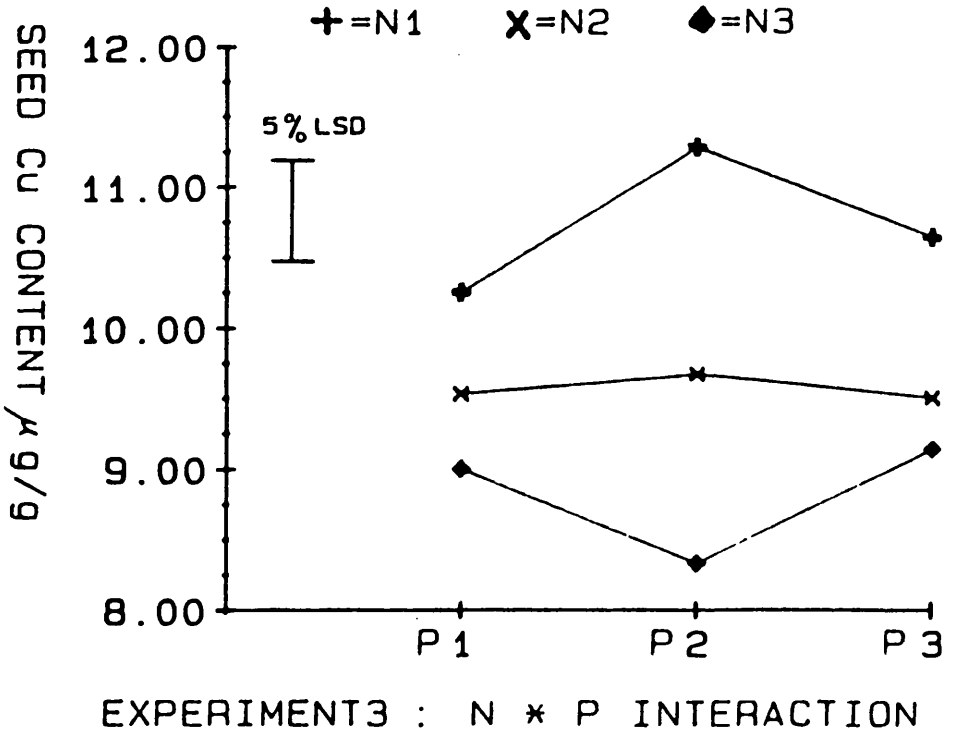

Figure 112. The effect of N x P interaction on seeds' total copper content.

From the analysis of variance presented in Table 59 it can be seen that the total seed copper content was significnatly affected by levels of N and the N x P interaction at 0.1% and 5.0% levels respectively.

As shown in Figure 111, the total seed copper content decreased with increasing levels of N in the order of $N_1 > N_2 > N_3$.

Figure 112 shows the effect of N and P interaction on seeds' total copper content. The highest seed copper was achieved by the combination N_1P_2 (11.28 µg per g) and the lowest by N_3P_2 (8.33 µg per mg) in this experiment.

4.3.7.4 Experiment 4: Total Seed Copper Content

The total seed copper content was determined in seed samples (Section 3.2.2) from each treatment in order to examine the effect of N and K mineral nutrition levels on seed Cu content and to attempt to establish a relationship between seed yield and quality.

Total nutrient levels (mg per plant)	Cu (µg per g)	Total nutrient levels (mg per plant)	Cu (µg per g)
N_1 = 0	5.60	K_1 = 0	4.50
N_2 = 100	5.15	K_2 = 50	4.83
N_3 = 500	4.15	K_3 = 250	4.98
N_4 = 1000	3.85	K_4 = 500	4.44

Significance levels:

N: 0.1% K: N.S., and their interaction Nx K: N.S.

5% LSD = 0.74

Table 60. The effect of N and K nutrition levels on total seed copper content in Experiment 4.

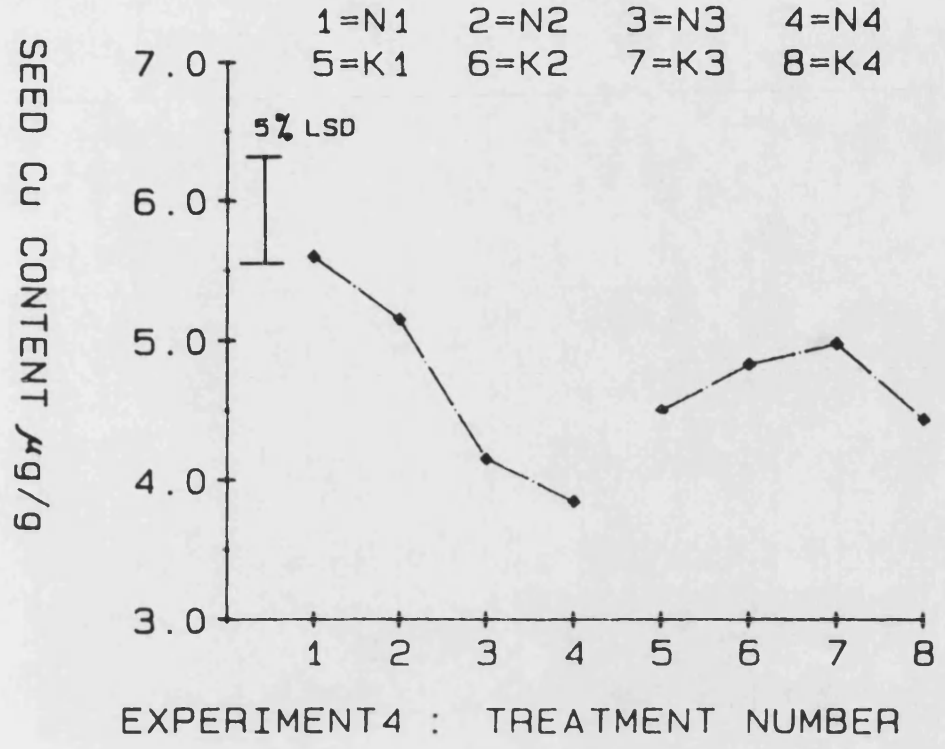

Figure 113. The effect of N and K mineral nutrition levels on seeds' total copper content.

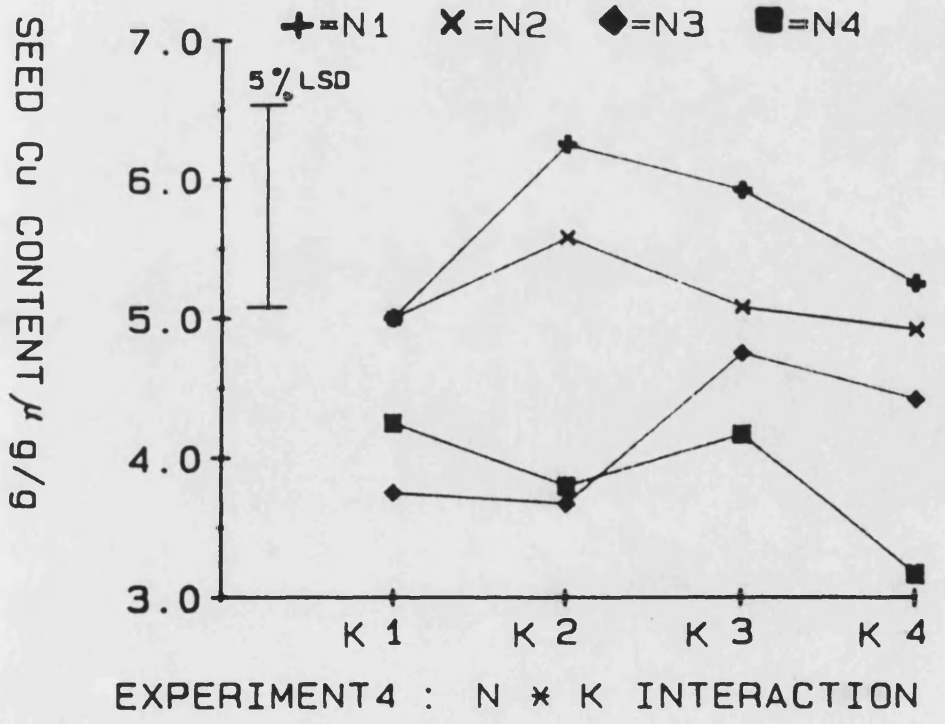

Figure 114. The effect of N and K interaction on seeds' total copper content.

From the analysis of variance presented in Table 60, it can be seen that only levels of N significantly affected the total seed copper content at the 0.1% level.

As shown in Figure 113, the total seed copper content decreased with increasing levels of N in the order of $N_1 > N_2 > N_3 > N_4$ in this experiment.

Figure 114 shows the effect of NK interaction on seeds' total copper content.

4.4 Seed Quality

4.4.1.1 Experiment 1: Mean seed weight (g)

The mean seed weight was calculated by dividing seed dry weight by seed number in each treatment in order to examine the effect of N, P and K mineral nutrition levels on seed quality as measured by seed size, assuming heavier seeds are larger.

Total nutrient levels (mg per plant)	Mean seed weight (g)	Total nutrient levels (mg per plant)	Mean Seed weight (g)	Total nutrient levels (mg per plant)	Mean seed weight (g)
N_1 = 100	0.216	P_1 = 50	0.234	K_1 = 40	0.236
N_2 = 150	0.223	P_2 = 70	0.217	K_2 = 60	0.218
N_3 = 300	0.241	P_3 = 140	0.228	K_3 = 120	0.225
N_4 = 500	0.224	P_4 = 210	0.225	K_4 = 180	0.275

Significance levels:

N: N.S. N x P: N.S.

P: 5.0% N x K: N.S. N x P x K: NS

K: N.S. P x K: N.S.

L.S.D. (N,P,K) = 0.011 (NxP,PxK,NxK) = 0.022 (N x P x K) = 0.044

Table 61. The effect of N, P and K mineral nutrition levels on mean seed weight in Experiment 1.

From the analysis of variance presented in Table 61 it can be seen that only levels of P significantly affected the mean seed weight at 5.0% significance level.

As shown in Figure 115, the mean seed weight increased with increasing levels of N up to N_3 and declined from N_3 to N_4 but not significantly and that increasing levels of P produced a sharp initial decline from P_1 to P_2 and then slowly rose afterwards in this experiment and in the order $N_3 > N_4 > N_2 > N_1$ and $P_1 > P_3 > P_4 > P_2$.

Figure 116 shows the effect of N and P interaction on mean seed weight.

4.4.1.2 Experiment 2: Mean seed weight (g)

The mean seed weight was calculated by dividing seed dry weight by seed number in each treatment in order to examine the effect of N and P mineral nutrition levels on seed quality as measured by seed size, assuming heavier seeds are larger. From the analysis of variance

Total nutrient levels (mg per plant)	Mean seed weight (g)	Total nutrient levels (mg per plant)	Mean seed weight (g)
N_1 = 100	0.141	P_1 = 25	0.140
N_2 = 1000	0.168	P_2 = 250	0.170
		P_3 = 500	0.163
		P_4 = 1000	0.145

Significance levels:

N:	0.1%	P: N.S.	N x P: N.S.
5% LSD	N: 0.019	P: 0.026	N x P: 0.037

Table 62. The effect of N and P nutrition levels on the mean seed weight in Experiment 2.

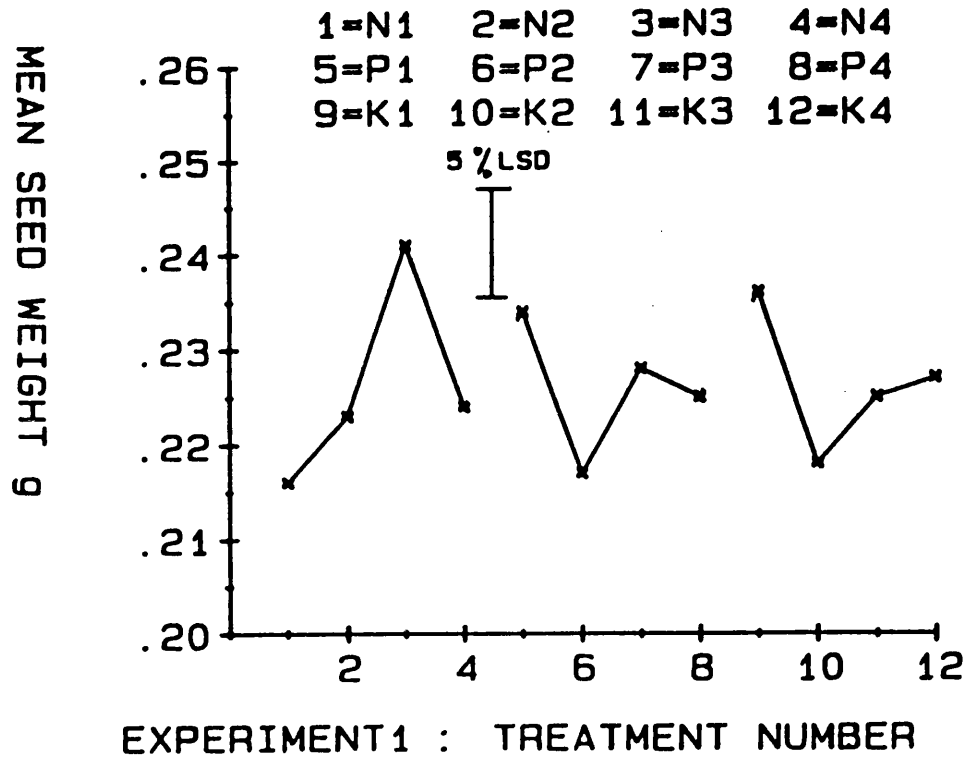

Figure 115. The main effect of N, P and K mineral nutrition levels on seed quality as determined by mean seed weight.

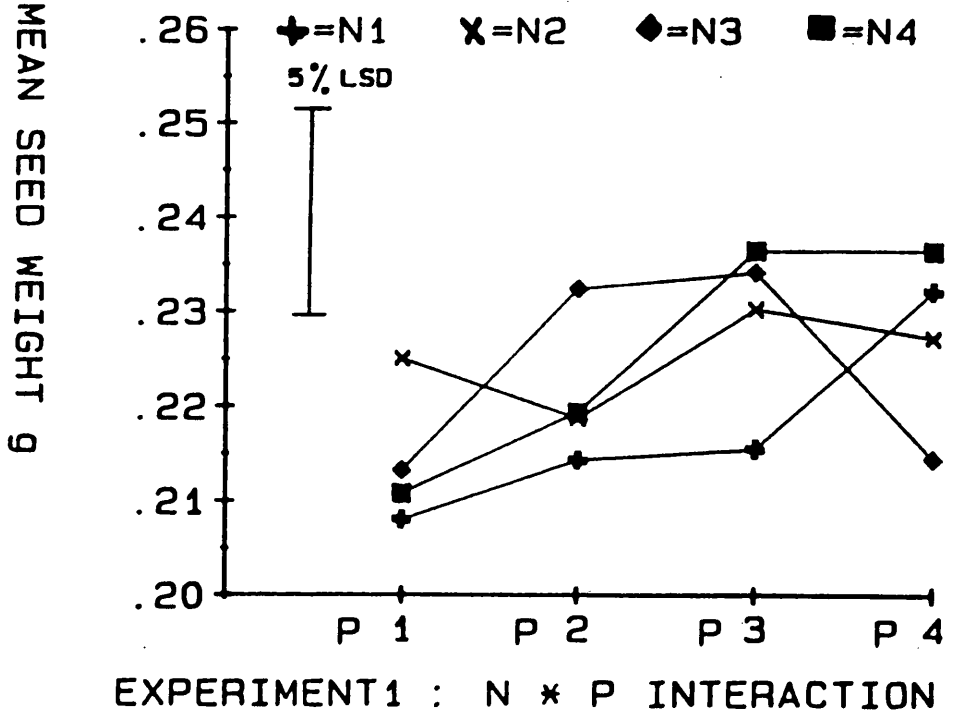

Figure 116. The effect of N and P interaction on mean seed weight.

presented in Table 62 it can be seen that only N levels significantly affected the mean seed weight at just 5.0% significance level in this experiment.

As shown in Figure 117, the mean seed weight increased with increasing levels of N, but not significantly and decreased with increasing P levels from P_2 to P_4 after an initial increase from P_1 to P_2 as shown in the order $P_2 > P_3 > P_4 > P_1$.

Figure 118 shows the effect of N and P interaction on mean seed weight.

4.4.1 a.3 Experiment 3: Mean seed weight (g)

The mean seed weight was calculated by dividing seed dry weight by seed number in each treatment in order to examine the effect of N, P and K mineral nutrition levels on seed quality as measured by seed size, assuming heavier seeds are larger.

Total nutrient levels (kg per ha)	Mean seed weight (g)	Total nutrient levels (kg per ha)	Mean seed weight (g)	Total nutrient levels (kg per ha)	Mean seed weight (g)
$N_1 = 0$	0.183	$P_1 = 0$	0.184	$K_1 = 0$	0.186
$N_2 = 25$	0.183	$P_2 = 50$	0.188	$K_2 = 25$	0.183
$N_3 = 75$	0.188	$P_3 = 150$	0.183	$K_3 = 75$	0.186

Significance levels:

N: N.S. N x P: N.S.

P: N.S. N x K: N.S. N x P x K: NS

K: N.S. P x K: N.S.

L.S.D. 5%
(N,P,K) = 0.008 (NxP,PxK,NxK) = 0.014 (N x P x K) = 0.025

Table 63. The effect of N, P and K nutrition levels on mean seed weight (g) in Experiment 3.

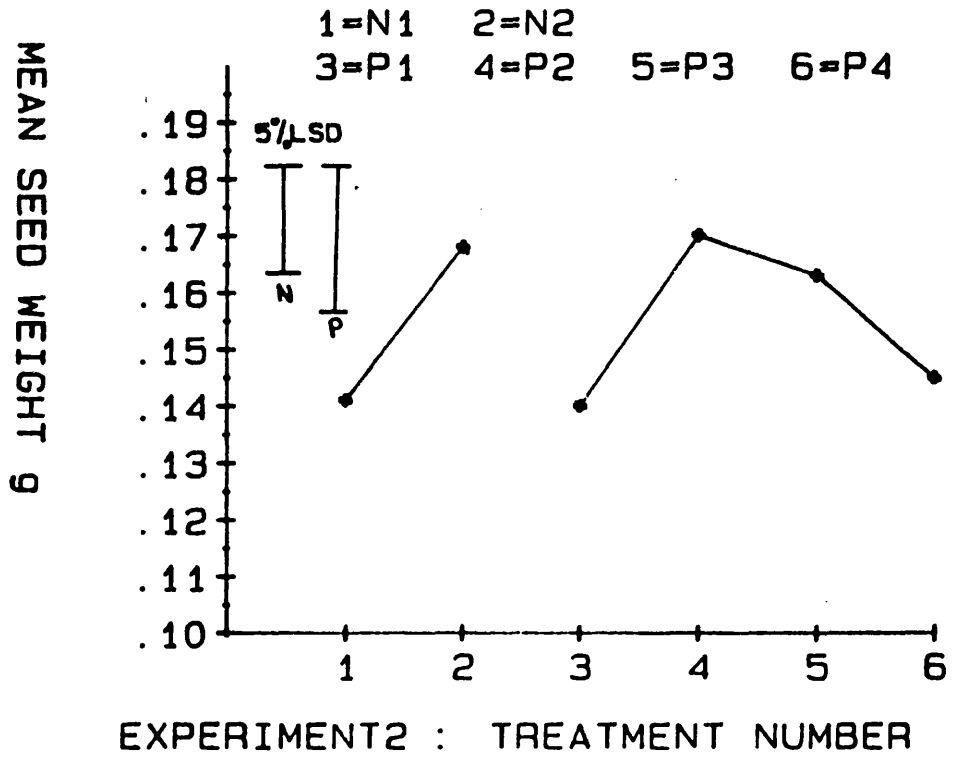

Figure 117. The main effect of N and P mineral nutrition on the seed quality as determined by the mean seed weight.

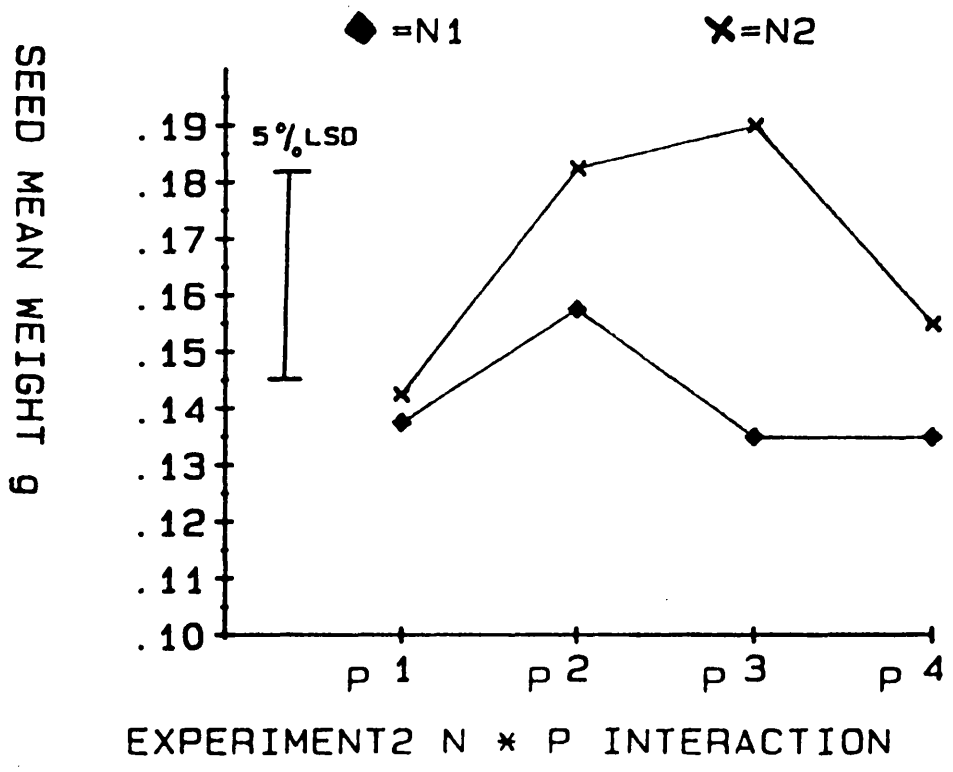

Figure 118. The effect of N and P interaction on the mean seed weight.

From the analysis of variance presented in Table 63 it can be seen that N, P and K and their interactions had no significant effect on mean seed dry weight.

Figure 119 shows the main effect of N, P and K nutrition on the mean seed dry weight in this experiment.

Figure 120 shows the effect of N and P interactions on mean seed weight.

4.4.1b.3.Experiment 3: 1000 seed dry weight (g)

One thousand seeds from each treatment were randomly selected and their dry weight recorded in order to examine the effect of N, P and K nutrition levels on seed quality as determined by 1000 seed dry weight.

Total nutrient levels (kg per ha)	1000 seed dry weight (g)	Total nutrient levels (kg per ha)	1000 seed dry weight (g)	Total nutrient levels (kg per ha)	1000 seed dry weight (g)
N_1 = 0	184.1	P_1 = 0	184.8	K_1 = 0	186.5
N_2 = 25	185.9	P_2 = 50	189.0	K_2 = 25	184.3
N_3 = 75	188.5	P_3 = 150	184.7	K_3 = 75	187.6

Significance levels:

N: N.S. N x P: N.S.

P: N.S. N x K: N.S. N x P x K: NS

K: N.S. P x K: N.S.

L.S.D.5% (N,P,K) = 8.49 (NxP,PxK,NxK) = 14.71 (N x P x K) = 25.48

Table 64. The effect of N, P and K nutrition levels on 1000 seed dry weight in Experiment 3.

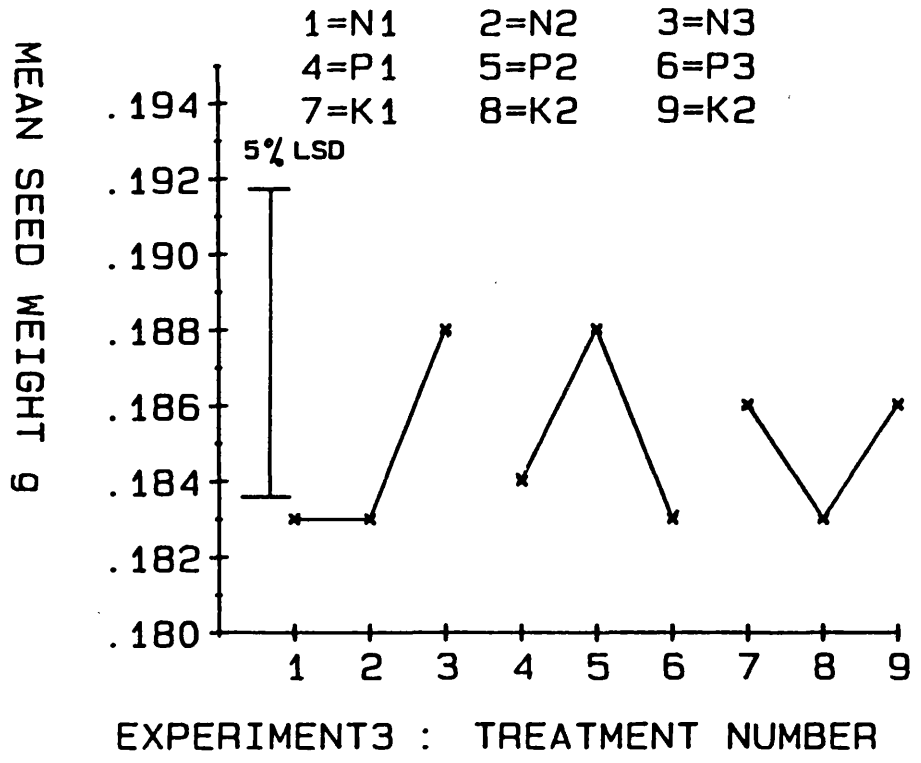

Figure 119. The main effect of N, P and K mineral nutrition levels on seed quality as determined by the mean seed weight.

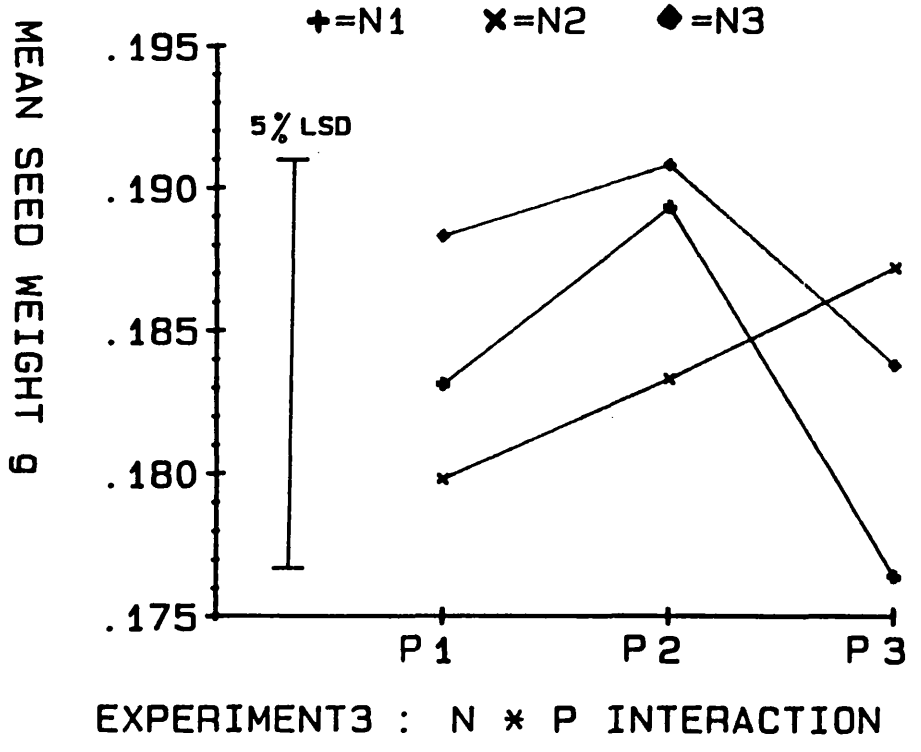

Figure 120. The effect of N and P interaction on the mean seed weight.

From the analysis of variance presented in Table 64 it can be seen that N, P, K and their interactions had no significant effect on 1000 seed dry weight.

Figure 121 shows the main effect of N, P and K nutrition on 1000 seed dry weight in this experiment.

Figure 122 shows the effect of N and P interaction on 1000 seed dry weight.

4.4.1.4 Experiment 4: Mean seed weight (g)

The mean seed weight was calculated by dividing seed dry weight by seed number in each treatment in order to examine the effect of N and K mineral nutrition levels on seed quality as measured by seed size, assuming heavier seeds are larger. From the analysis of variance presented in Table 65, it can be seen that only K levels

Total nutrient levels (mg per plant	Mean seed weight (g)	Total nutrient levels (mg per plant)	Mean seed weight (g)
N_1 = 0	0.208	K_1 = 0	0.179
N_2 = 100	0.207	K_2 = 50	0.199
N_3 = 500	0.211	K_3 = 250	0.226
N_4 = 1000	0.211	K_4 = 500	0.233

Significance levels:

N: N.S. K: 0.1% and their interaction NxK: N.S.

5% LSD = 0.008

Table 65. The effect of N and K nutrition levels on mean seed weight (g) in Experiment 4.

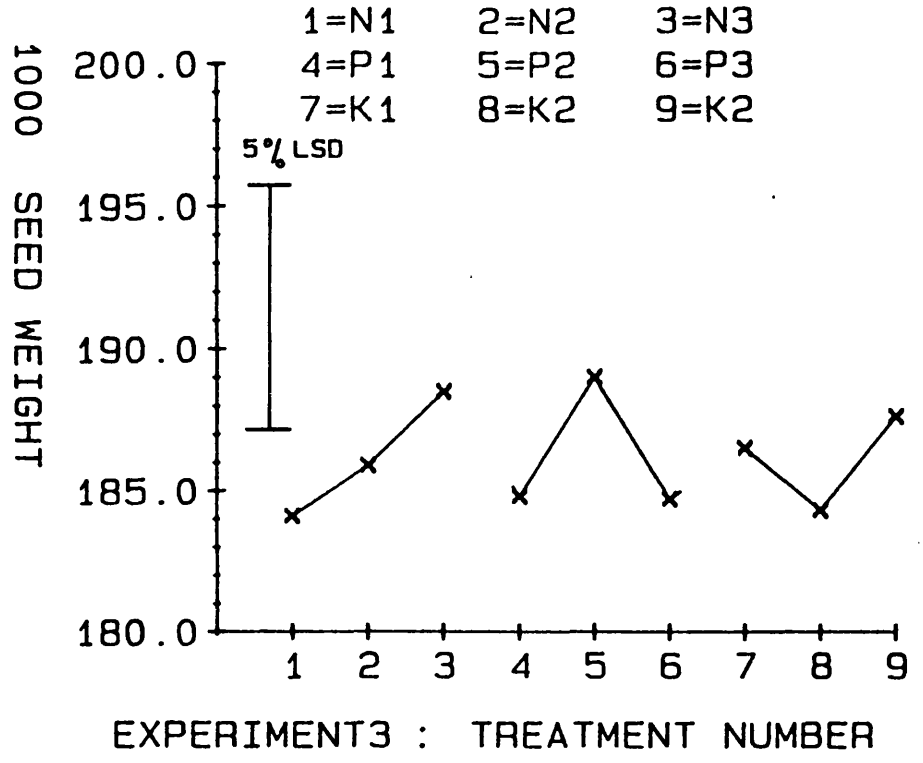

Figure 121. The effect of N, P and K mineral nutrition levels on seed quality as determined by 1000 seed weight.

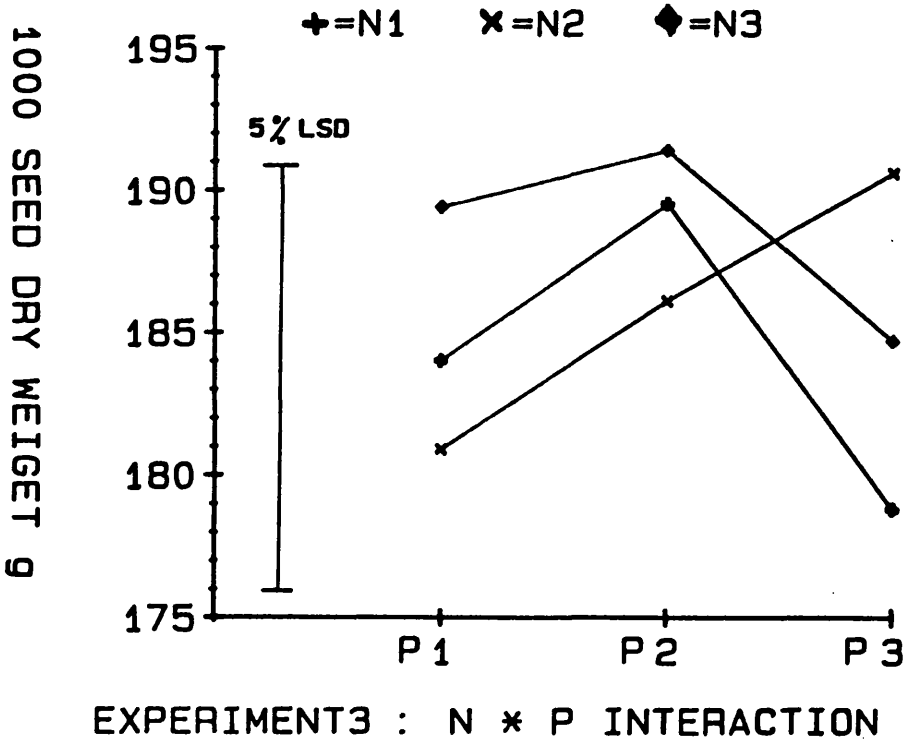

Figure 122. The effect of N and P interaction on 1000 seed dry weight.

significantlly affected the mean seed weight at 0.1% level. Whereas levels of N nor the N and K interaction had no significant effect.

As shown in Figure 123, mean seed weight increased with increasing levels of K nutrition in the order of $K_1 < K_2 < K_3 < K_4$ in this experiment.

Figure 124 shows the effect of N and K interaction on mean seed weight.

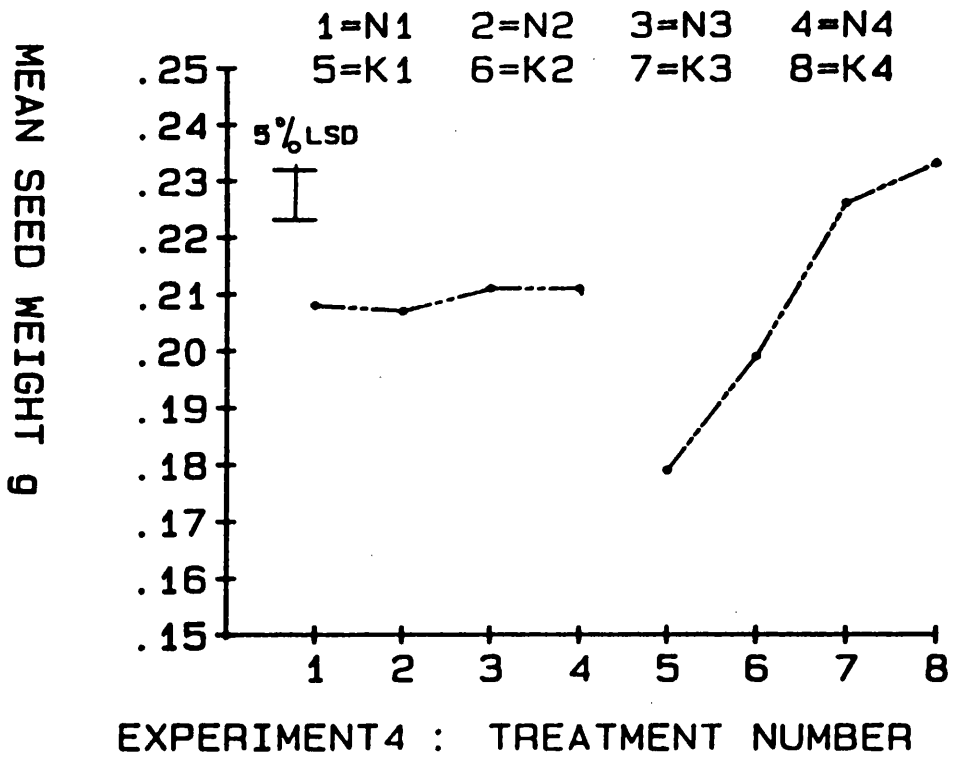

Figure 123. The main effect of N and K mineral nutrition levels on seed quality as determined by mean seed weight.

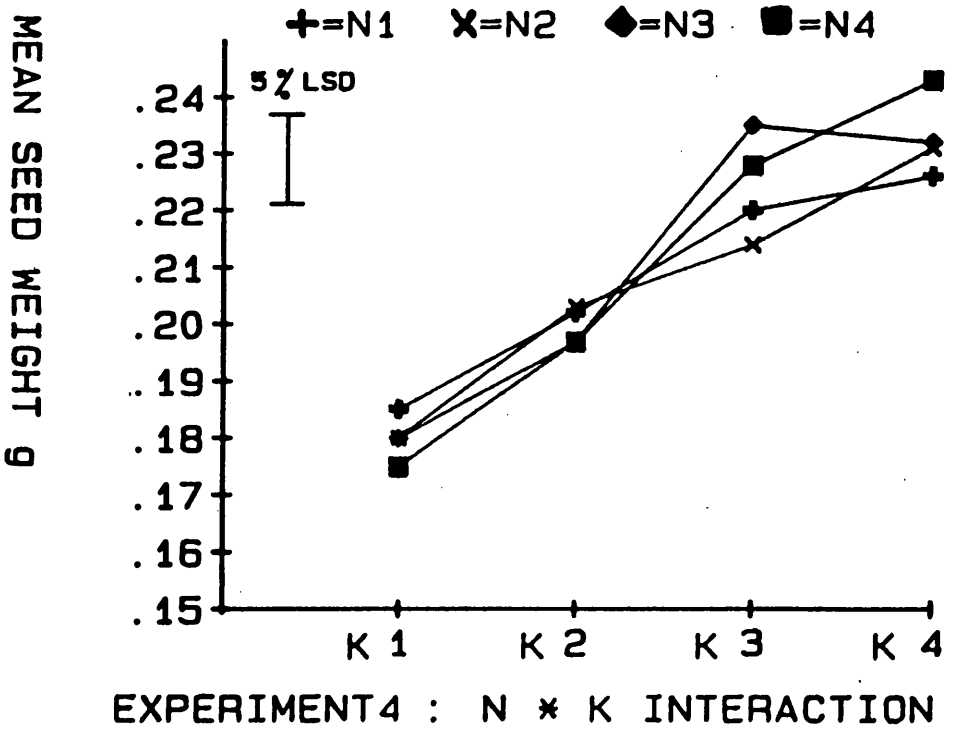

Figure 124. The effect of N and K interaction on mean seed weight.

4.4.2.1 Experiment 1: % Germination in the Germination Test

The percentage germination of the seeds during the standard germination test was recorded in order to examine the effect of N, P and K nutrition levels on seed quality as determined by the germination test. From the analysis of variance presented in Table

Total nutrient levels (mg per plant)	Percent germ-ination	Total nutrient levels (mg per plant)	Percent germin-ation	Total nutrient levels (mg per plant)	Percent germin-ation
N_1 = 100	98.53	P_1 = 50	97.91	K_1 = 40	98.25
N_2 = 150	98.75	P_2 = 70	99.25	K_2 = 60	97.94
N_3 = 300	98.41	P_3 = 140	98.19	K_3 = 120	98.66
N_4 = 500	97.47	P_4 = 210	97.81	K_4 = 180	98.31

Significance levels:

N: N.S. N x P: 5%

P: 5% Nx K: 5% N x P x K: 5%

K: N.S. P x K: 1%

L.S.D. (N,P,K) = 1.11 (NxP,PxK,NxK) = 2.21 (N x P x K) = 4.42

Table 66. The effect of N, P and K mineral nutrition levels on % germination in the germination test in Experiment 1.

66, it can be seen that only the levels of P and the interactions NP, NK, PK and NPK significantly affected the percentage germination at the 5% significance level apart from the PK interaction, which was at the 1.0% level.

As shown in Figure 125, the levels of P decreased the percentage germination as they increased, after an initial increase from P_1 to P_2 and that levels of N also decreased the percentage germination as they increased but not significantly in this experiment, in the order of $N_2 > N_1 > N_3 > N_4$ and $P_2 > P_3 > P_1 = P_4$.

Figures 126, 127, 128 show the effect of the NP, NK and PK interaction on the percentage germination.

4.4.2.2 Experiment 2: % germination in the Germination Test

The percentage germination of the seeds during the standard germination test was recorded, in order to examine the effect of N and P nutrition levels on seed quality as determined by the germination test. From the analysis of variance presented in Table 67 it can be

Total nutrient levels (mg per plant)	% germination	Total nutrient levels (mg per plant)	% Germination
N_1 = 100	99.00	P_1 = 25	88.57
N_2 = 1000	90.67	P_2 = 250	96.00
		P_3 = 500	98.67
		P_4 = 1000	96.00

Significance levels:

N:	0.1%	P: 1.0%	N x P: 1.0%
5% LSD	N: 2.00	P: 2.46	N x P: 4.01

Table 67. The effect of N and P nutrition levels on the percentage germination in the germination test in Experiment 2.

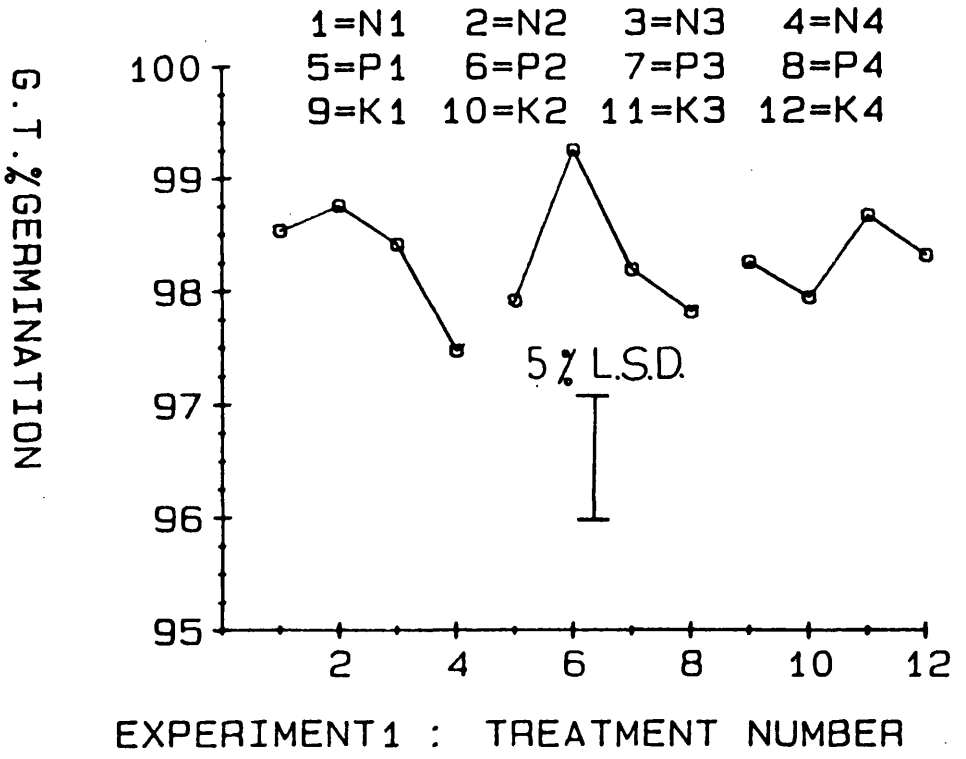

Figure 125. The main effect of N, P and K mineral nutrition levels on seed quality as determined by the percentage germination in the germination test.

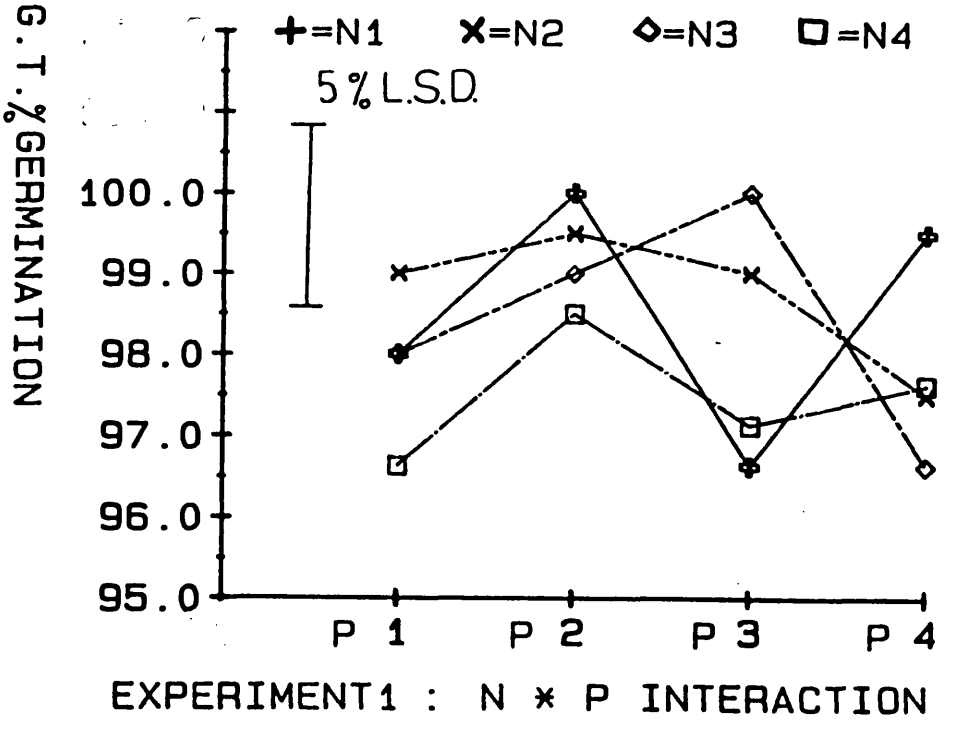

Figure 126. The effect of N and P interaction on the percentage germination in the germination test.

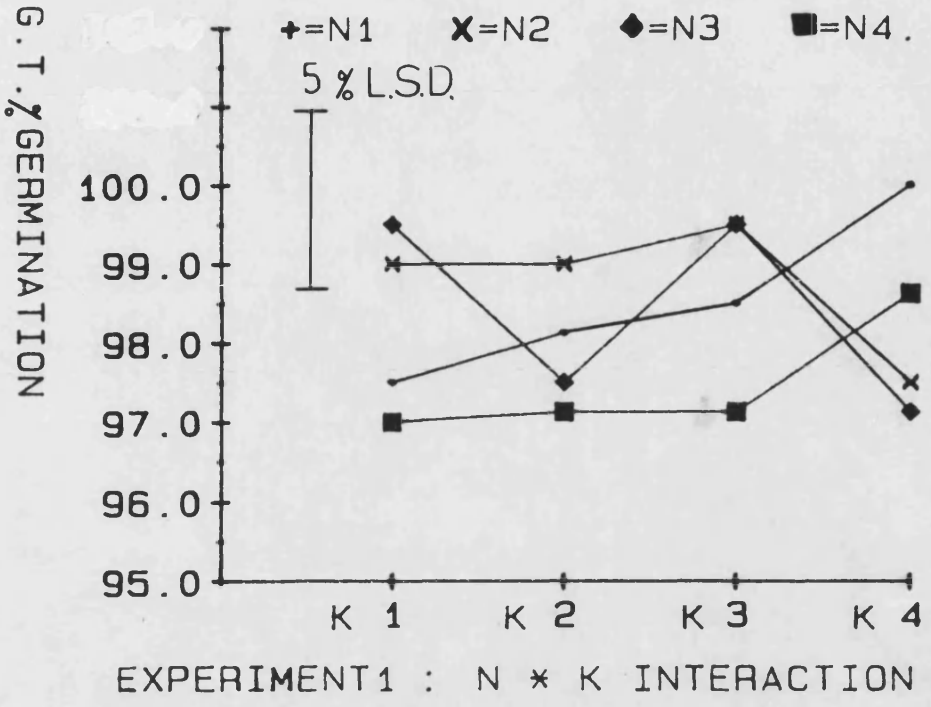

Figure 127. The effect of N and K interaction on the percentage germination in the germination test.

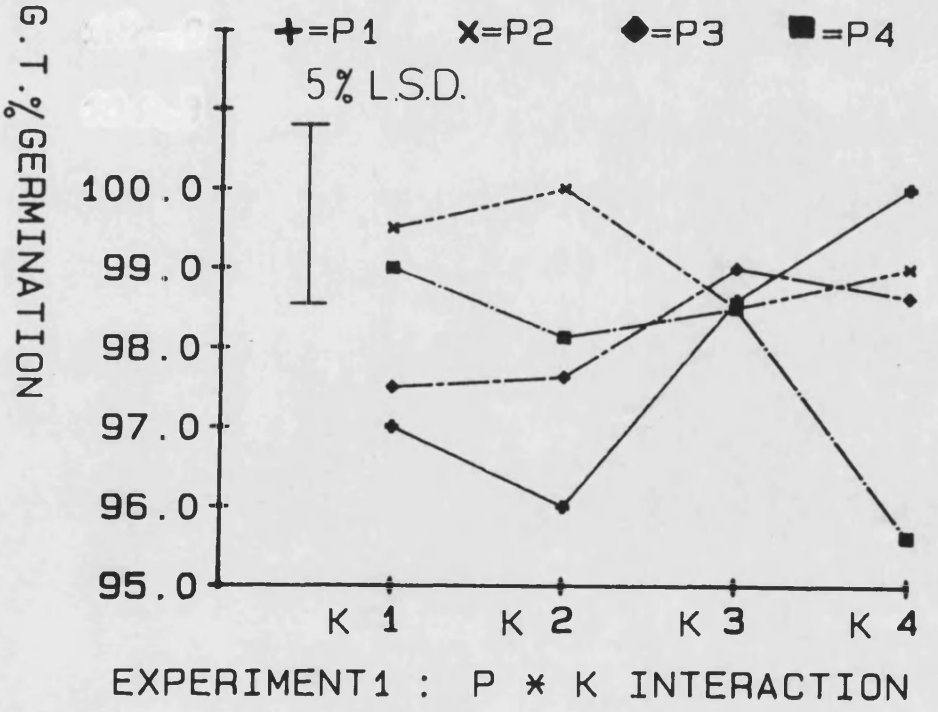

Figure 128. The effect of P and K interaction on the percentage germination in the germination test.

seen that levels of N, P and their interactions N x P significantly affected the percentage germination at the 0.1% significance level.

As shown in Figure 129, the germination percentage decreased with increasing levels of N and increased with increasing levels of P up to P_3 and slightly declined from P_3 to P_4, in this experiment in the orders $N_1 > N_2$ and $P_3 > P_2 > P_4 > P_1$.

Figure 130 shows the effect of N and P interaction on the % germination. The highest germination percentage was achieved by the combination N_1P_3 (100%) and the lowest by N_2P_1 (78.67%).

4.4.2.3 Experiment 3: Percentage germination in the germination test

The percentage germination of the seeds during the standard germination test was recorded in order to examine the effect of N, P and K nutrition levels on seed quality as determined by the

Total nutrient levels (kg per ha)	Percent germination	Total nutrient levels (kg per ha)	Percent germination	Total nutrient levels (kg per ha)	Percent germination
N_1 = 0	87.48	P_1 = 0	86.89	K_1 = 0	86.81
N_2 = 25	85.33	P_2 = 50	86.07	K_2 = 25	84.74
N_3 = 75	84.96	P_3 = 150	84.87	K_3 = 75	86.22

Significance levels:

N: N.S. N x P: 5.0%

P: N.S. N x K: N.S. N x P x K: NS

K: N.S. P x K: N.S.

L.S.D. 5%

(N,P,K) = 2.97 (NxP,PxK,NxK) = 5.14 (N x P x K) = 15.80

Table 68. The effect of N, P and K nutrition levels on percentage germination in the germination test in Experiment 3.

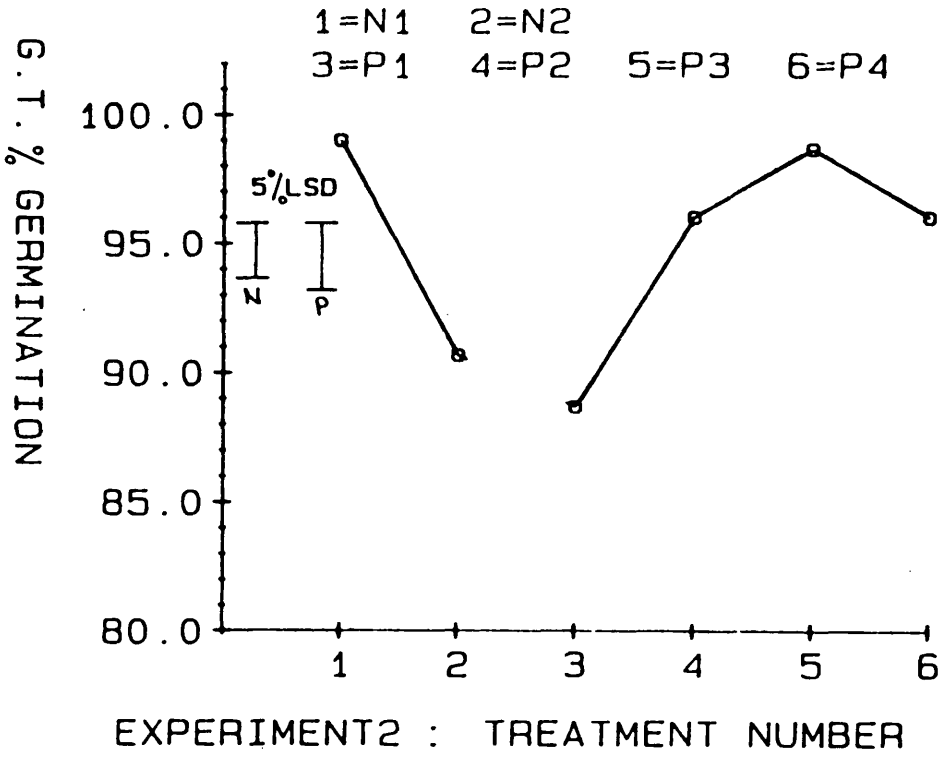

Figure 129. The main effect of N and P mineral nutrition on seed quality as determined by the germination test.

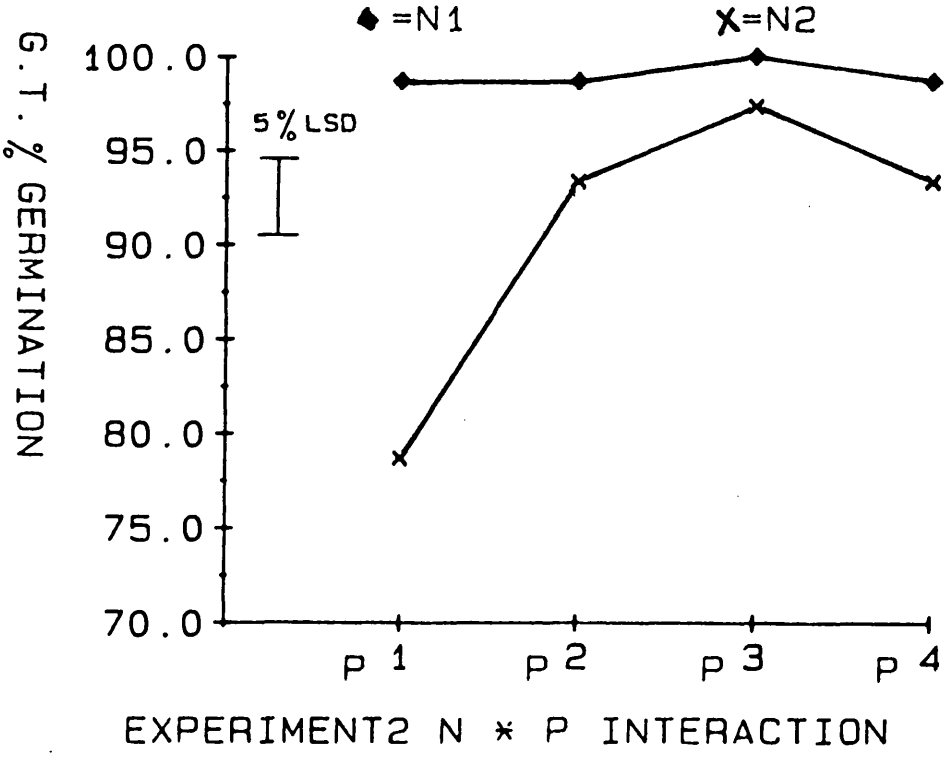

Figure 130. The effect of N and P interaction on the seed germination during the germination test.

germination test. From the analysis of variance presented in Table 68, it can be seen that the percentage germination was only significantly affected by the N x P interaction at the 5.0% level.

Figure 131 shows the effect of N and P interaction on the percentage germination during the germination test. The highest germination percentage was achieved by the combination N_1P_2 (91.11%) and the lowest by N_2P_2 (82.00%) in this experiment.

4.4.2.4 Experiment 4: Percentage germination in the germination test

The percentage germination of the seeds during the standard germination test was recorded, in order to examine the effect of N and K nutrition levels on seed quality as determined by the germination test. From the analysis of variance presented in Table 69,

Total nutrient levels (mg per plant)	% germination	Total nutrient levels (mg per plant)	% germination
N_1 = 0	97.53	K_1 = 0	94.00
N_2 = 100	96.50	K_2 = 50	93.33
N_3 = 500	97.67	K_3 = 250	91.17
N_4 = 1000	97.17	K_4 = 500	93.50

Significance levels:

N: N.S. K: N.S. and their interaction N x K: N.S.

5% LSD = 2.55

Table 69. The effect of N and K nutrition levels on percentage germination in the germination test in Experiment 4.

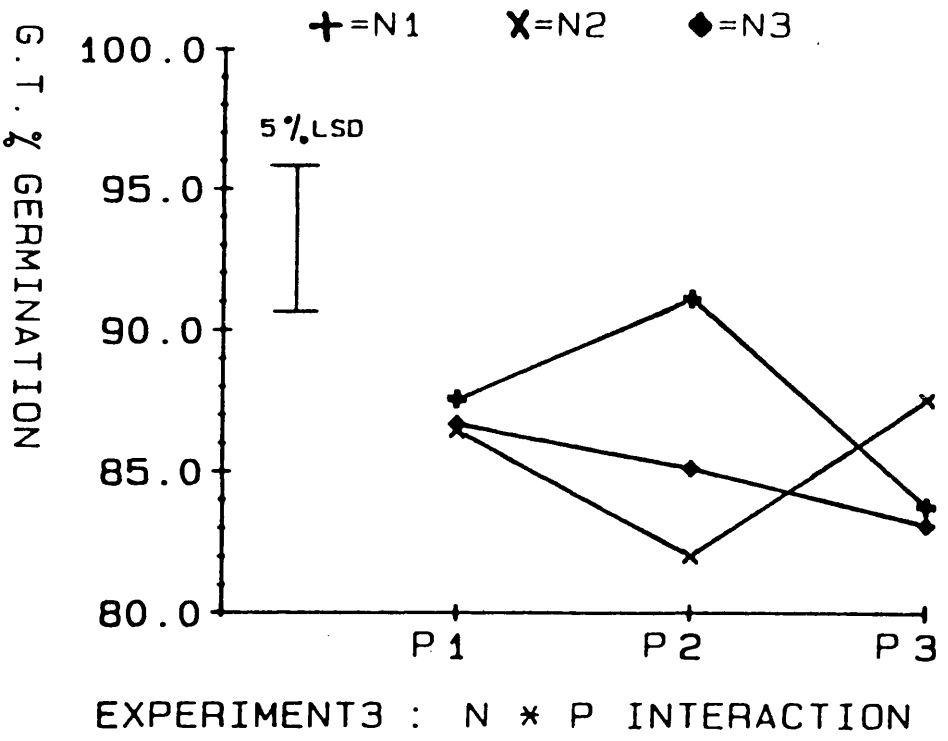

Figure 131. The effect of N x P interaction on percentage germination in the germination test.

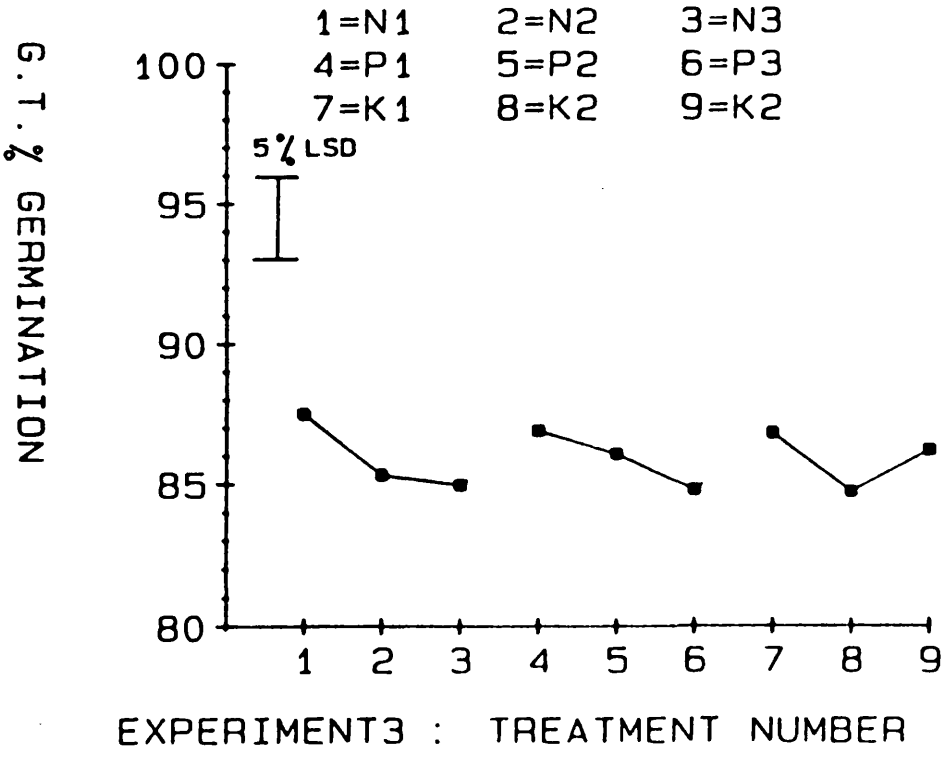

Figure 132. The main effect of N, P and K mineral nutrition levels on seed quality as determined by the percentage germination during the germination test.

it can be seen that the percentage of germination was not affected by levels of N, K or their interaction N x K.

Figure 133 shows the main effect of N and K levels on the percentage germination during the germination test in this experiment.

Figure 134 shows the effect of N and K interaction on the percentage germination during the germination test.

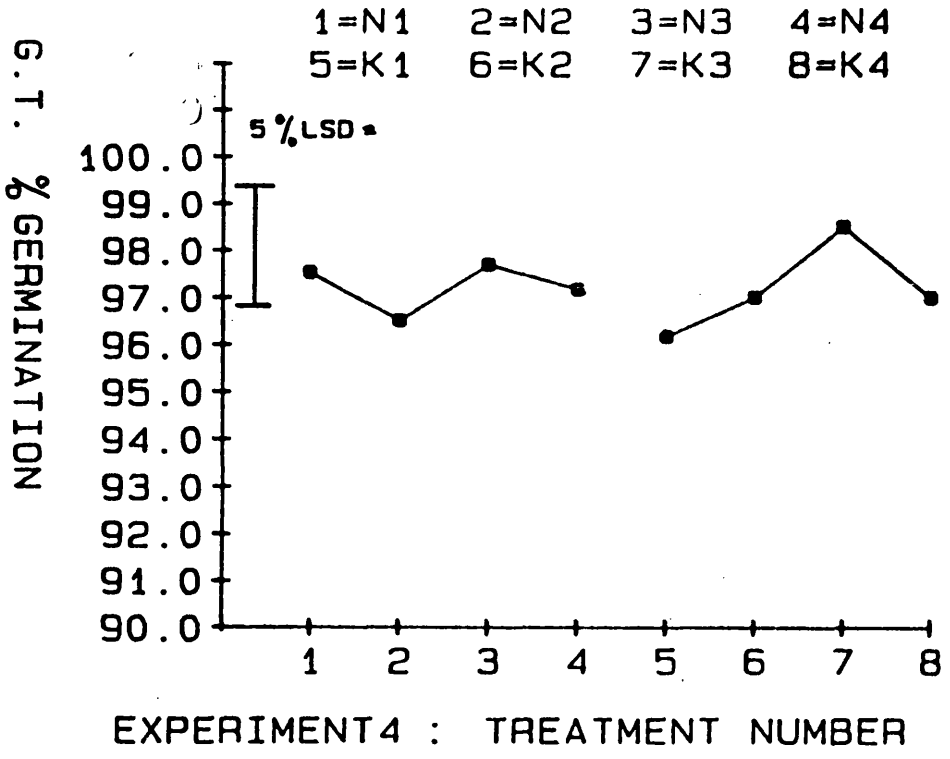

Figure 133. The main effect of N and K mineral nutrition levels on seed quality as determined by the percentage germination during the germination test.

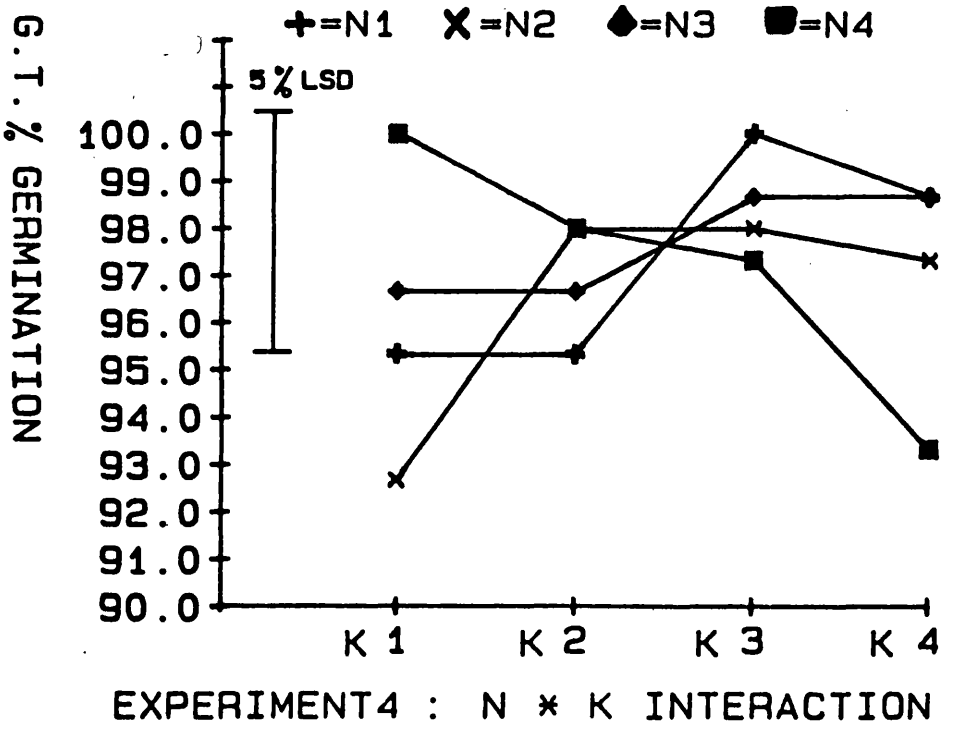

Figure 134. The effect of N and K interaction on the percentage germination in the germination test.

4.4.3.1 Experiment 1: Seedling dry weight; germination test

The seedling dry weight of total seedlings in the germination test was recorded after the completion of the test in order to examine the effect of N, P and K nutrition on seed vigour as determined by seedling dry weight. From the analysis of variance

Total nutrient levels (mg per plant)	Weight (g)	Total nutrient levels (mg per plant)	Weight (g)	Total nutrient levels (mg per plant	Weight (g)
N_1 = 100	0.3622	P_1 = 50	0.3012	K_1 = 40	0.3287
N_2 = 150	0.3253	P_2 = 70	0.3294	K_2 = 60	0.3528
N_3 = 300	0.2859	P_3 = 140	0.3456	K_3 = 120	0.3203
N_4 = 500	0.3466	P_4 =210	0.3438	K_4 = 180	0.3181

Significance levels:

N: 0.1% N x P: 5.0%

P: 5% N x K: 0.1% N x P x K: 1.0%

K: N.S. P x K: N.S.

L.S.D. (N,P,K) = 0.031 (NxP,PxK,NxK) = 0.062 (N x P x K) = 0.123

Table 70. The effect of N, P and K mineral nutrition on the seedling dry weight on completion of the germination test in Experiment 1.

presented in Table 70 it can be seen that the seedling dry weight was significantly affected by the levels of N and P and the interactions NP, NK and NPK at 0.1%, 5.0%, 5.0%, 0.1% and 1.0% significance levels respectively.

As shown in Figure 135, the seedling dry weight decreased with increasing levels of N up to N_3 and then sharply increased from N_3 to N_4, but it increased steadily with increasing levels of P in this experiment and in the orders of $N_1 > N_4 > N_2 > N_3$, $P_3 > P_4 > P_2 > P_1$ and $K_2 > K_1 > K_3 > K_4$.

Figures 136 and 137 show the effect of NP and NK interactions on the seedling dry weight. The highest seedling dry weight was achieved by the combination N_1P_4 (0.423 g) in the NP interaction and by N_1K_2 (0.411 g) in the NK interaction and the lowest seedling dry weight was achieved by the combination N_3P_1 (0.259 g) in the NP interactions and by the N_3K_3 (0.229 g) in the NK interaction.

In the NPK interaction the highest seedling dry weight was achieved by the combinations $N_1P_4K_3$ and $N_4P_4K_1$ (0.490 g) and the lowest by $N_3P_2K_3$ (0.200 g).

4.4.3.2 Experiment 2: Seedling dry weight; Germination test

The seedling dry weight of the total seedlings in the germination test was recorded after the completion of the test in order to examine the effect of N and P nutrition on seed vigour as determined by seedling dry weight. From the ansalysis of variance presented in Table 71, it can be seen that the seedling dry weight was significantly affected by the levels of P and the N and P interaction at 0.1% and 1.0% significance levels respectively.

As shown in Figure 138, seedling dry weight increased with increasing levels of N but not significantly and also increased with increasing levels of P up to P_3 and then slightly decreased from P_3 to P_4 in this experiment and in the orders of $N_2 > N_1$ and $P_3 > P_2 > P_4 > P_1$.

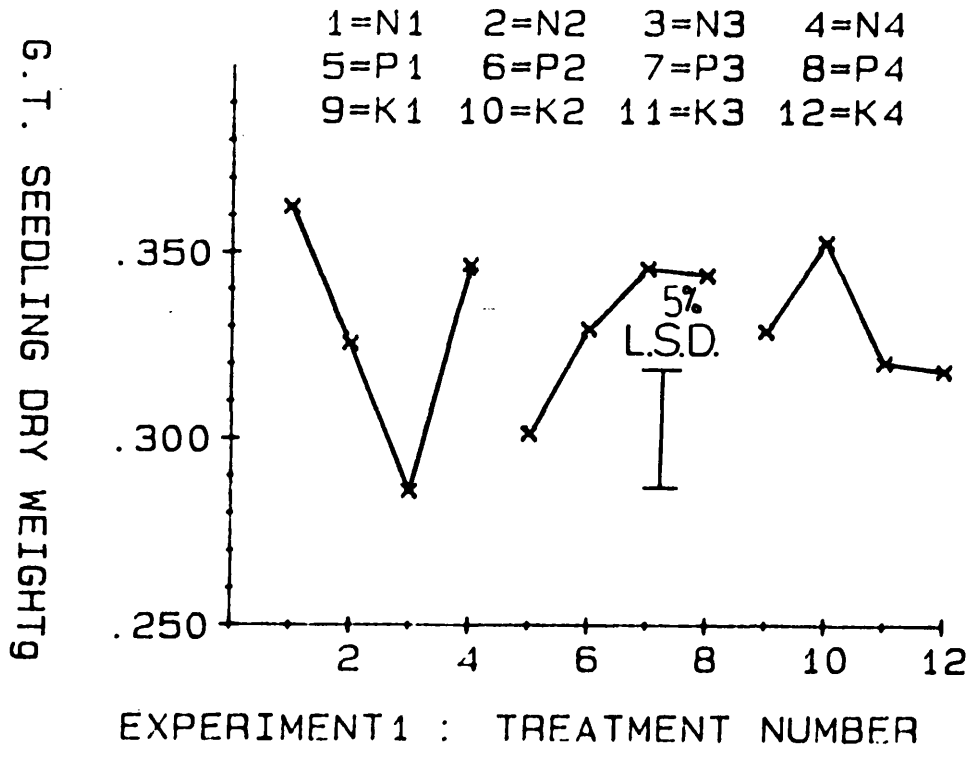

Figure 135. The main effect of N, P and K mineral nutrition levels on the seedling dry weight on completion of the germination test.

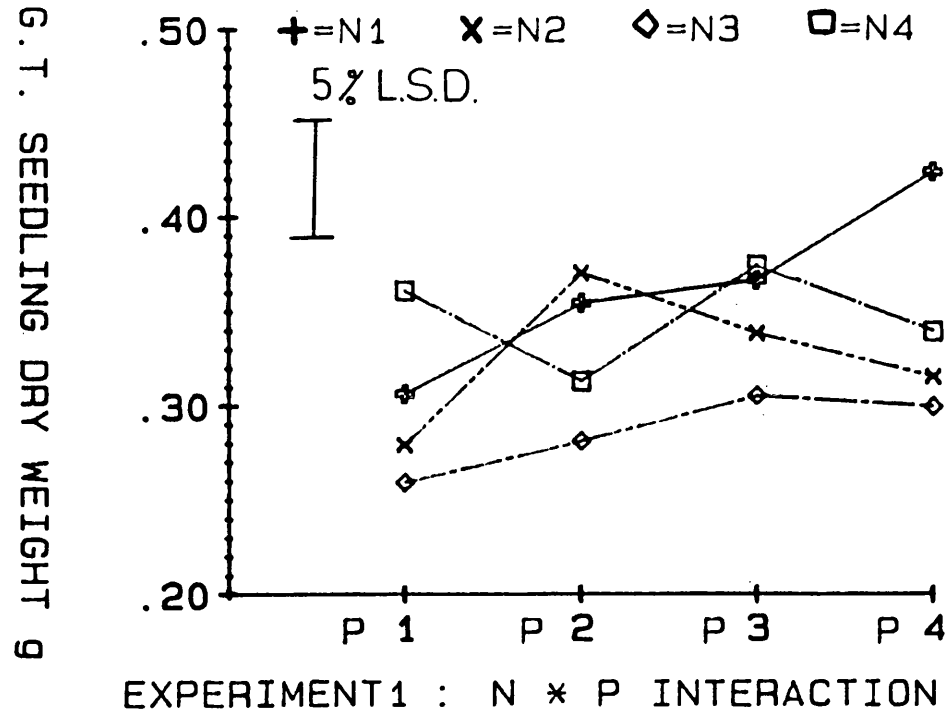

Figure 136. The effect of N and P interaction on the seedling dry weight on completion of the germination test.

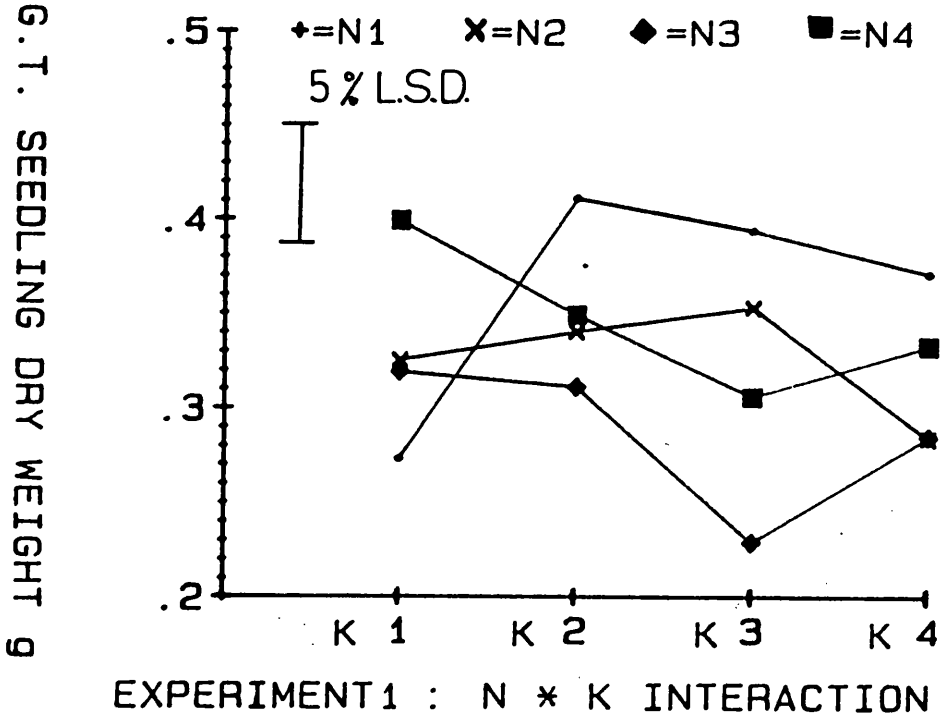

Figure 137. The effect of N and K interaction on the seedling dry weight on completion of the germination test.

Total nutrient levels (mg per plant)	Weight (g)	Total nutrient levels (mg per plant)	Weight (g)
N_1 = 100	0.4033	P_1 = 25	0.2767
N_2 = 1000	0.4317	P_2 = 250	0.4550
		P_3 = 500	0.4967
		P_4 = 1000	0.4417

Significance levels:

N:	N.S.	P: 0.1%	N x P: 1.0%
5% LSD	N: 0.057	P: 0.070	N x P: 0.114

Table 71. The effect of N and P nutrition levels on the seedling dry weight at completion of the germination test in Experiment 2.

Figure 139 shows the effect of N and P interaction on the seedling dry weight in the germination test. The highest seedling dry weight was achieved by the combination N_2P_3 (0.5767 g) and the lowest by N_2P_1 (0.2300 g).

4.4.3.3 Experiment 3: Seedling dry weight; germination test

The seedling dry weight of the total seedlings at the end of the germination test was recorded for each treatment in order to examine the effect of N, P and K nutrition on seed vigour as determined by the seedling dry weight. From the analysis of variance presented in Table 72 it can be seen that the seedling dry weight was not significantly affected by N, P, K or any of their

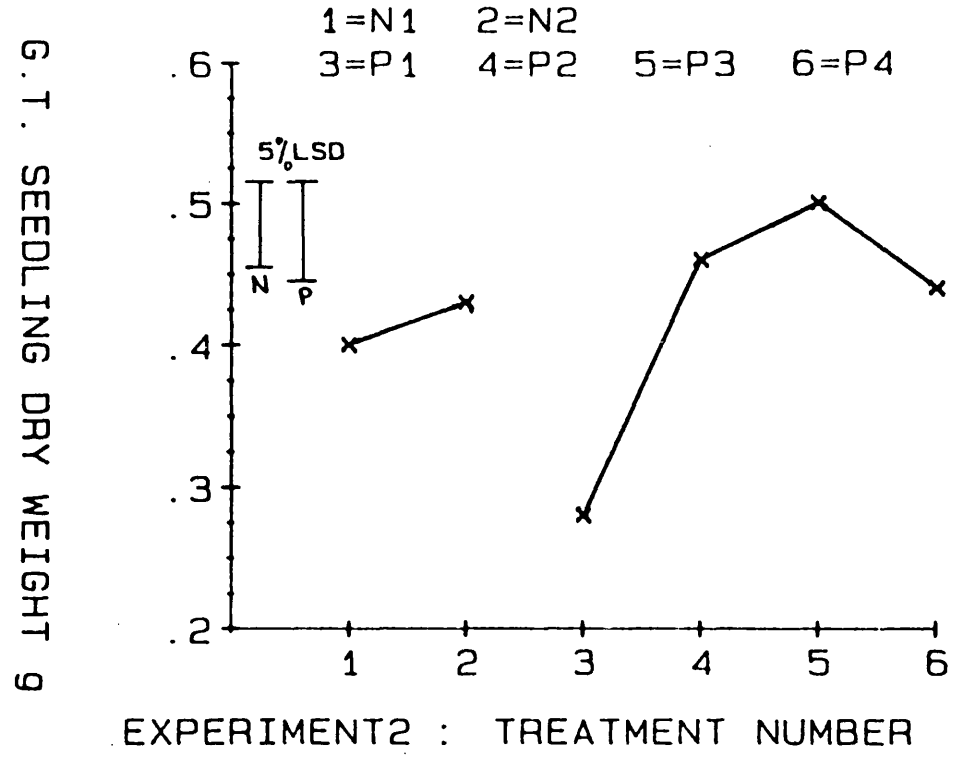

Figure 138. The main effect of N and P mineral nutrition levels on the seedling dry weight on completion of the germination test.

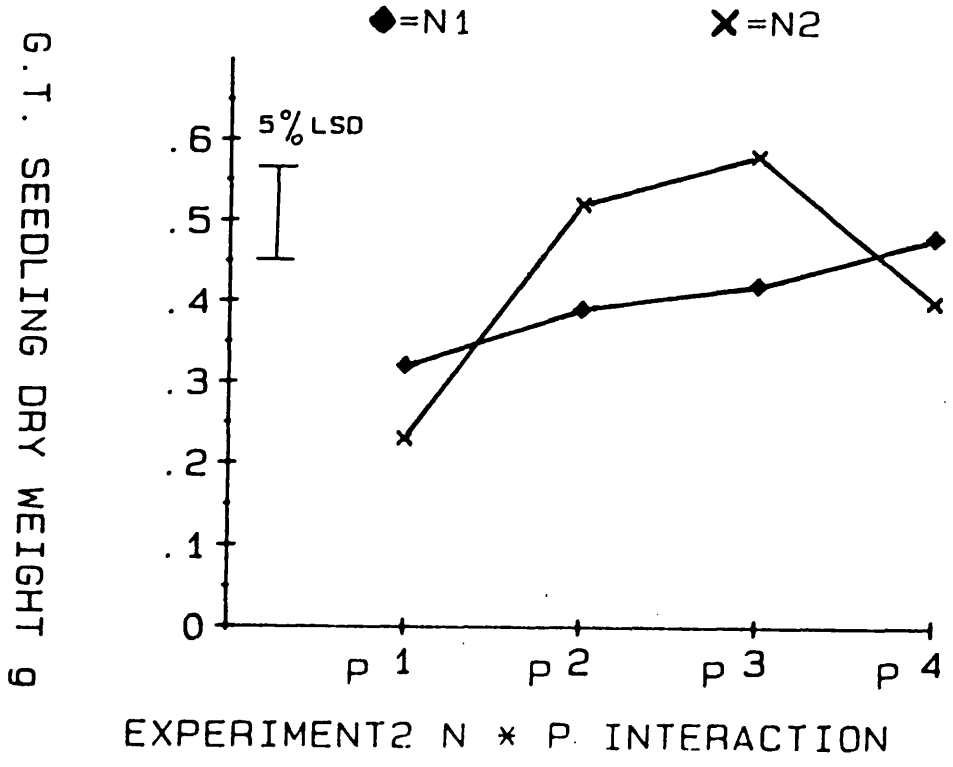

Figure 139. The effect of N and P interaction on seedling dry weight on completion of the germination test.

Total nutrient levels (kg per ha)	Weight (g)	Total nutrient levels (kg per ha)	Weight (g)	Total nutrient levels (kg per ha)	Weight (g)
N_1 = 0	0.981	P_1 = 0	0.992	K_1 = 0	0.987
N_2 = 25	0.977	P_2 = 50	0.993	K_2 = 25	0.964
N_3 = 75	0.984	P_3 = 150	0.956	K_3 = 75	0.991

Significance levels:

N: N.S. N x P: N.S.

P: N.S. N x K: N.S. N x P x K: NS

K: N.S. P x K: N.S.

L.S.D. 5%
(N,P,K) = 0.095 (NxP,PxK,NxK) = 0.164 (N x P x K) = 0.284

Table 72. The effect of N, P and K nutrition levels on the seedling dry weight on completion of the germination test in Experiment 3.

interactions in this experiment.

Figure 140 shows the main effect of N, P and K nutrition levels on seedling dry weight at the end of the germination test.

Figure 141 shows the effect of N and P interaction levels on seedling dry weight.

4.4.3.4 Experiment 4: Seedling dry weight; germination test

The seedling dry weight of the total seedlings in the germination test was recorded after the completion of the test in order to examine the effect of N and K nutrition on seed vigour as

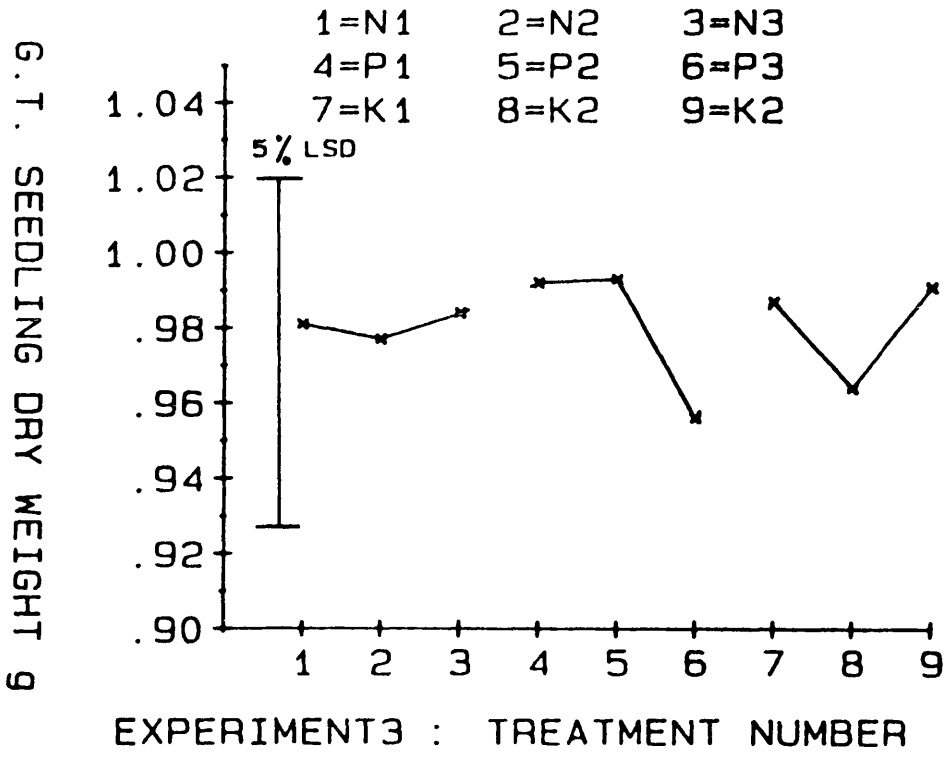

Figure 140. The main effect of N, P and K mineral nutrition levels on the seedling dry weight on completion of the germination test.

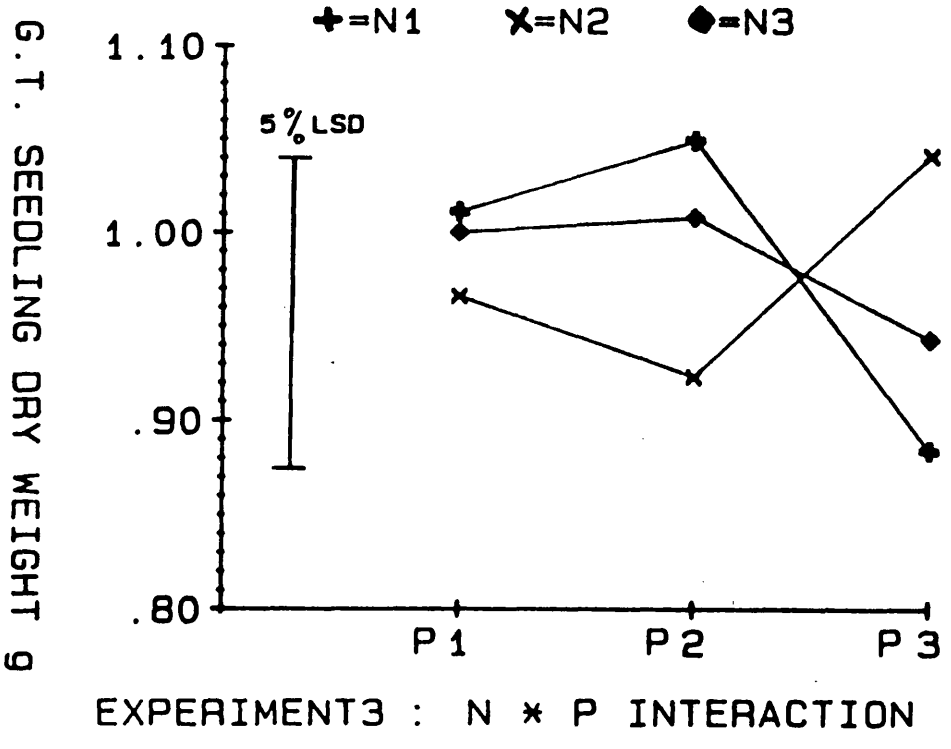

Figure 141. The effect of N and P interaction on seedling dry weight on completion of the germination test.

Total nutrient levels (mg per plant)	Weight (g)	Total nutrient levels (mg per plant)	Weight (g)
N_1 = 0	1.78	K_1 = 0	1.57
N_2 = 100	1.69	K_2 = 50	1.72
N_3 = 500	1.69	K_3 = 250	1.89
N_4 = 1000	1.86	K_4 = 500	1.84

Significance levels:

N: 5% K: 0.1%, and their interaction Nx K: N.S.

5% LSD = 0.125

Table 73. The effect of N and K nutrition levels on seedling dry weight on completion of the germination test in Experiment 4.

determined by seedling dry weight. From the analysis of variance presented in Table 73, it can be seen that the seedling dry weight is significantly affected by levels of N and K nutrition at the 5.0% and 0.1% levels respectively.

As shown in Figure 142, levels of N affected the seedling dry weight in the following order: $K_4 > K_1 > K_3 = K_2$ whereas the seedling dry weight increased by increasing K levels up to K_3 and slightly decreased by K_4, in the order of $K_1 < K_2 < K_3 > K_4$ in this experiment.

Figure 143 shows the effect of NK interaction on the seedling dry weight on completion of the germination test.

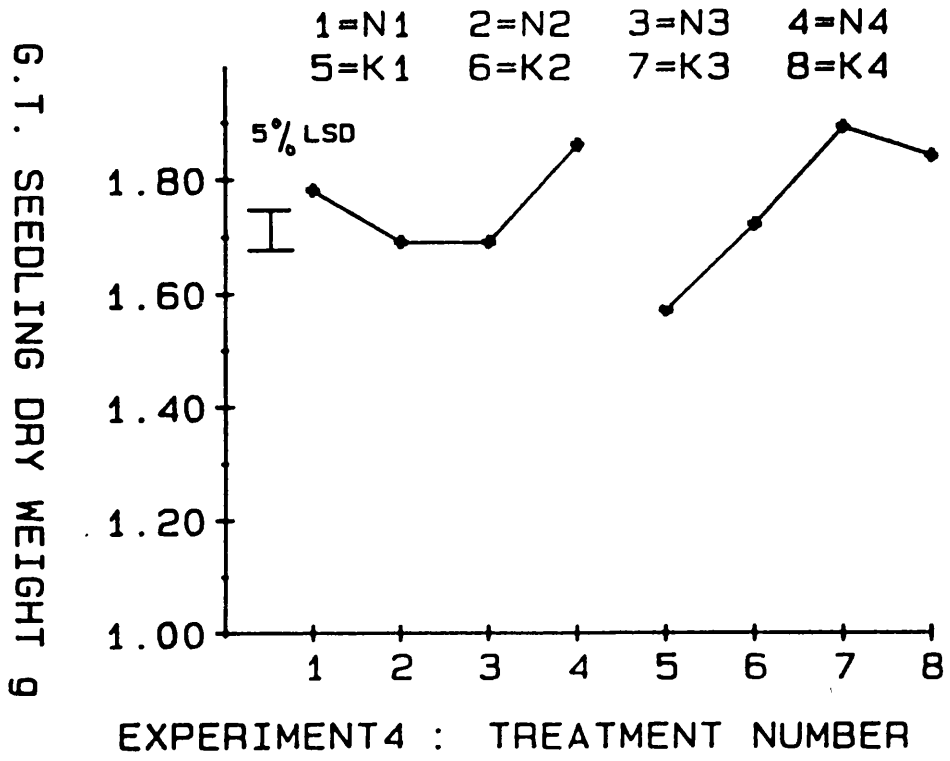

Figure 142. The main effect of N and K mineral nutrition levels on the seedling dry weight on completion of the germination test.

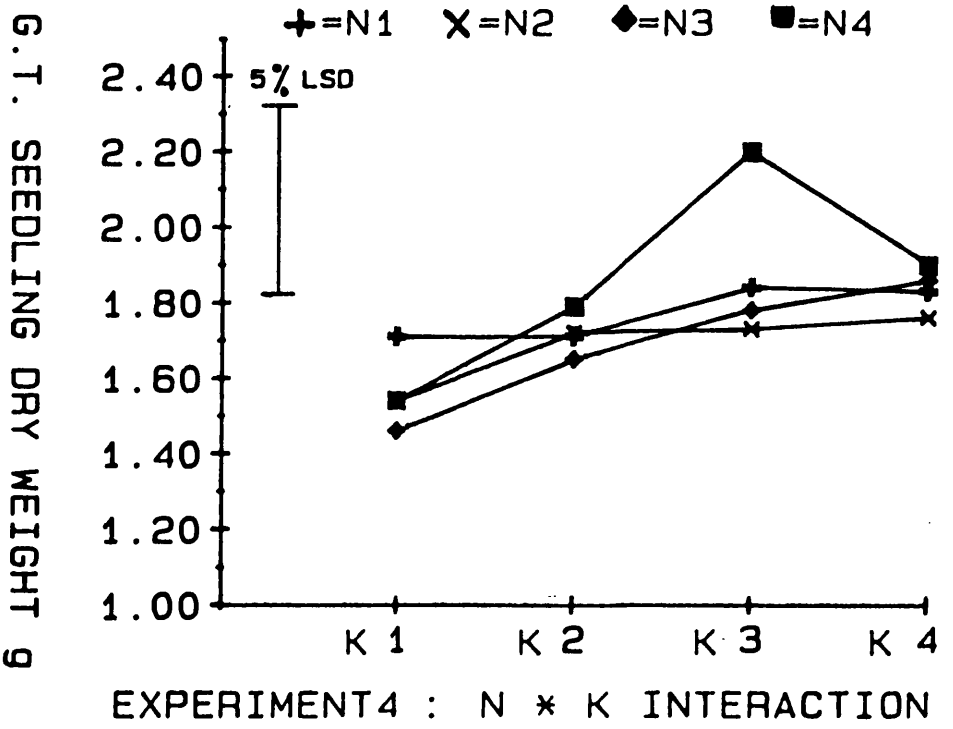

Figure 143. The effect of N and K interaction on the seedling dry weight on completion of the germination test.

4.4.4.1 Experiment 1: Seedling evaluation; percentage of normal seedlings

The percentage of normal seedlings after the final count of the germination test was recorded in order to examine the effect of N, P and K nutrition levels on seed vigour, as determined by the seedling evaluation. From the analysis of variance presented in

Total nutrient levels (mg per plant)	% normal seed-lings	Total nutrient levels (mg per plant)	% normal seed-lings	Total nutrient levels (mg per plant	% normal seed-lings
N_1 = 100	67.3	P_1 = 50	70.4	K_1 = 40	67.1
N_2 = 150	69.0	P_2 = 70	68.0	K_2 = 60	72.0
N_3 = 300	65.6	P_3 = 140	67.0	K_3 = 120	68.4
N_4 = 500	69.0	P_4 =210	65.5	K_4 = 180	63.4

Significance levels:

N: N.S. N x P: N.S.

P: N.S. N x K: 5.0% N x P x K: 5.0%

K: 5.0% P x K: 1.0%

L.S.D. (N,P,K) = 5.19 (NxP,PxK,NxK) = 10.37 (N x P x K) = 20.74

Table 74. The effect of N, P and K mineral nutrition levels on the percentage of normal seedlings on completion of the germination test in Experiment 1.

Table 74, it can be seen that the percentage of normal seedlings was significantly affected by levels of K and the interactions NK, PK and

NPK levels at 5% significance levels except for PK which was at 1.0%.

As shown in Figure 144, the percentage of normal seedlings decreased with both increasing levels of P and K after an initial increase from K_1 to K_2 in this experiment and in the orders of $N_4 = N_2 > N_1 > N_3$, $P_1 > P_2 > P_3 > P_4$ and $K_2 > K_3 > K_1 > K_4$.

Figures 145 and 146 show the effect of NK and PK interaction on the percentage of normal seedlings. The highest percentage was obtained in the interactions NK by N_2K_3 (76.52%) and in PK by P_4K_1 (85.0%) and the lowest by N_3K_4 (61.52%) in the NK interaction and by P_4K_4 54.52%in the PK interaction.

In the NPK interaction the highest percentage normal seedlings was achieved by the combinations $N_2P_1K_2$ and $N_4P_1K_4$ (88%) and the lowest by $N_3P_4K_3$ (44.0%).

4.4.4.2 Experiment 2: Seedling evaluation; percentage normal seedlings

The percentage of normal seedlings after the final count of the germination test was recorded in order to examine the effect of N and P nutrition levels on seed vigour as determined by the seedling evaluation. From the analysis of variance presented in Table 75, it can be seen that the percentage of normal seedlings was only significantly affected at levels of 0.1% significance.

As shown in Figure 147 the percentage normal seedlings decreased with increasing levels of N and it decreased with increasing levels of P after an initial increase from P_1 to P_2 but not significantly in this experiment and in the order of $N_1 > N_2$ and $P_2 > P_3 > P_4 > P_1$.

Figure 148 shows the effect of NP interaction on the percentage of normal seedlings.

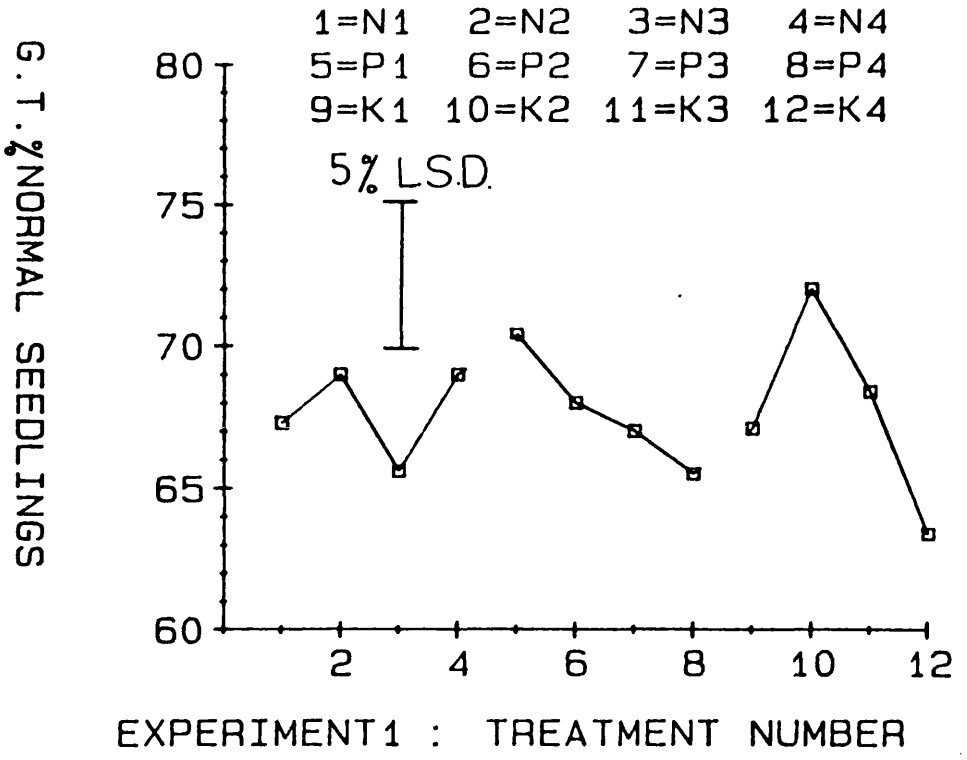

Figure 144. The main effect of N, P and K mineral nutrition levels on seed vigour as determined by the percentage of normal seedlings on completion of the germination test.

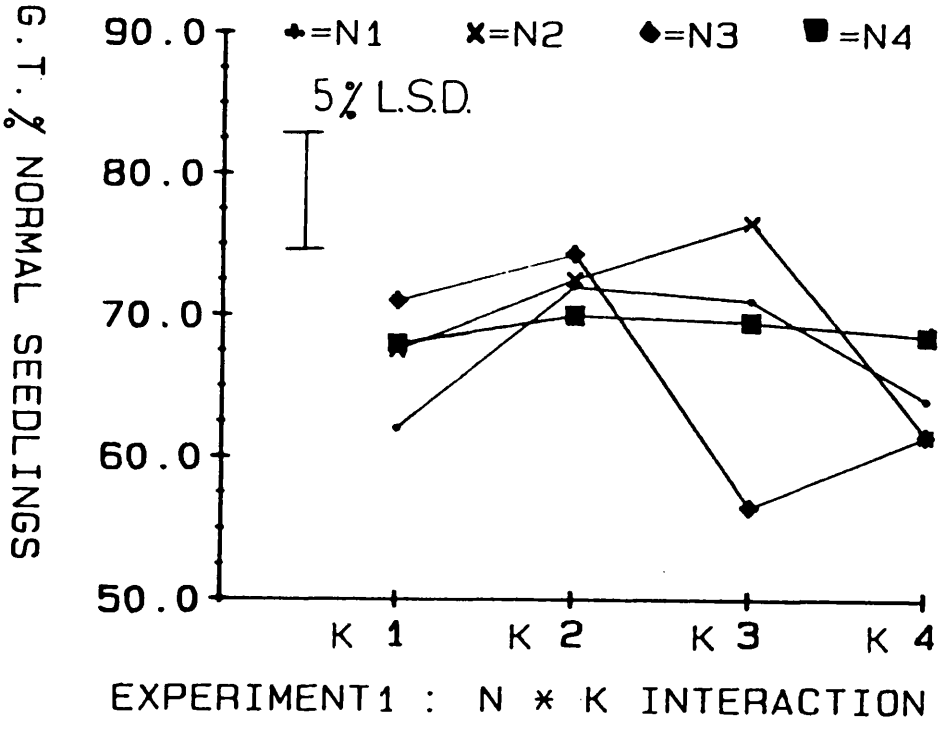

Figure 145. The effect of N and K interaction on the percentage normal seedlings on completion of the germination test.

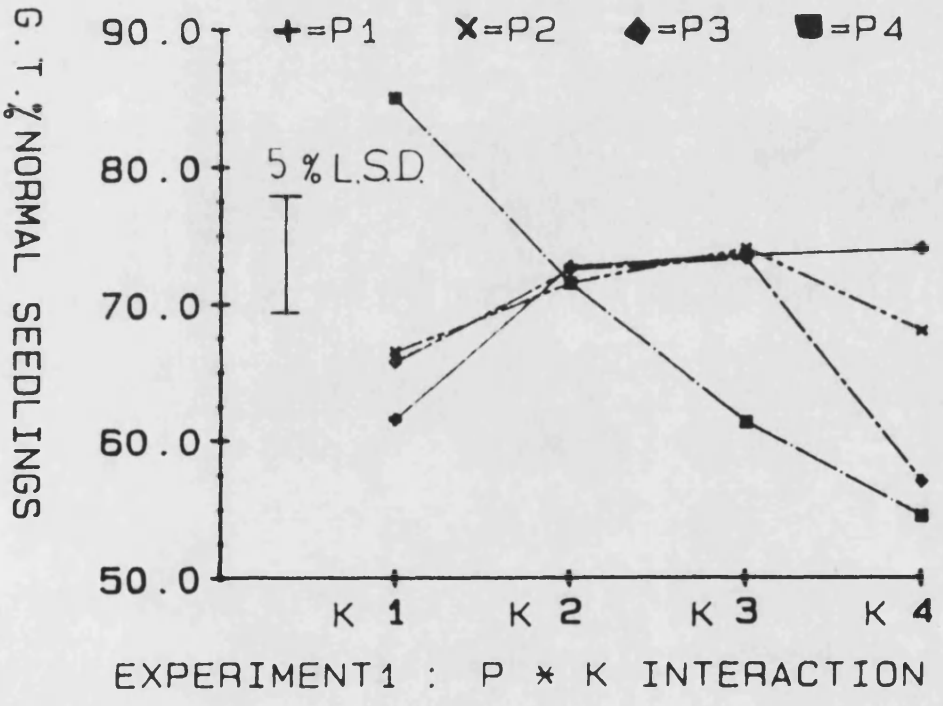

Figure 146. The effect of P and K interaction on the percentage of normal seedlings on completion of the germination test.

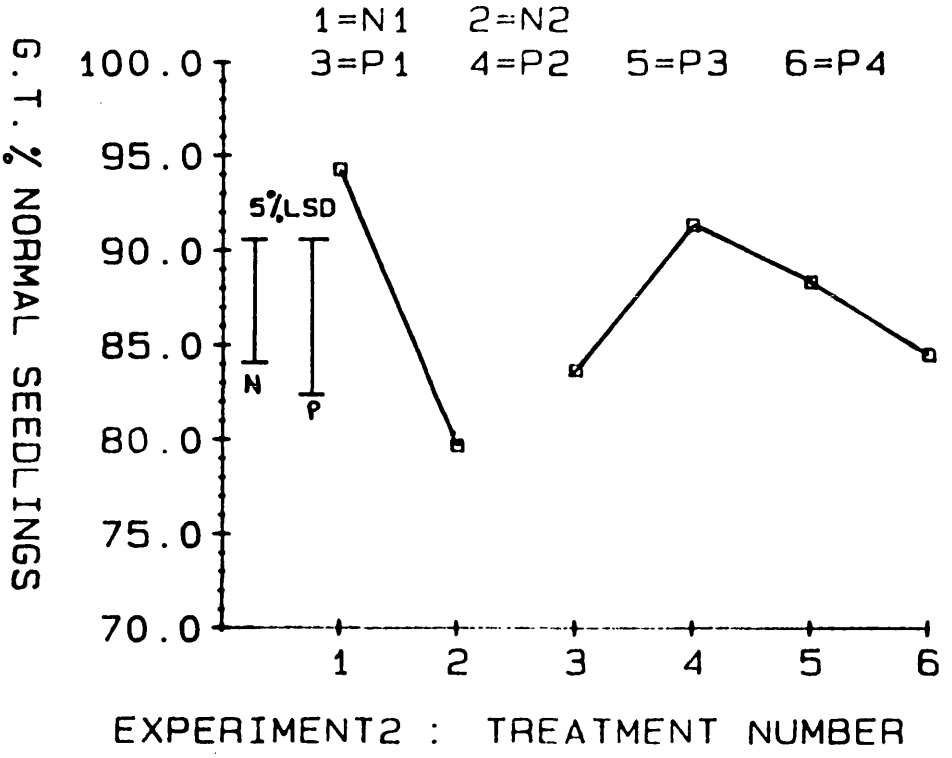

Figure 147. The main effect of N and P mineral nutrition levels on seed vigour as determined by the percentage of normal seedlings on completion of the germination test.

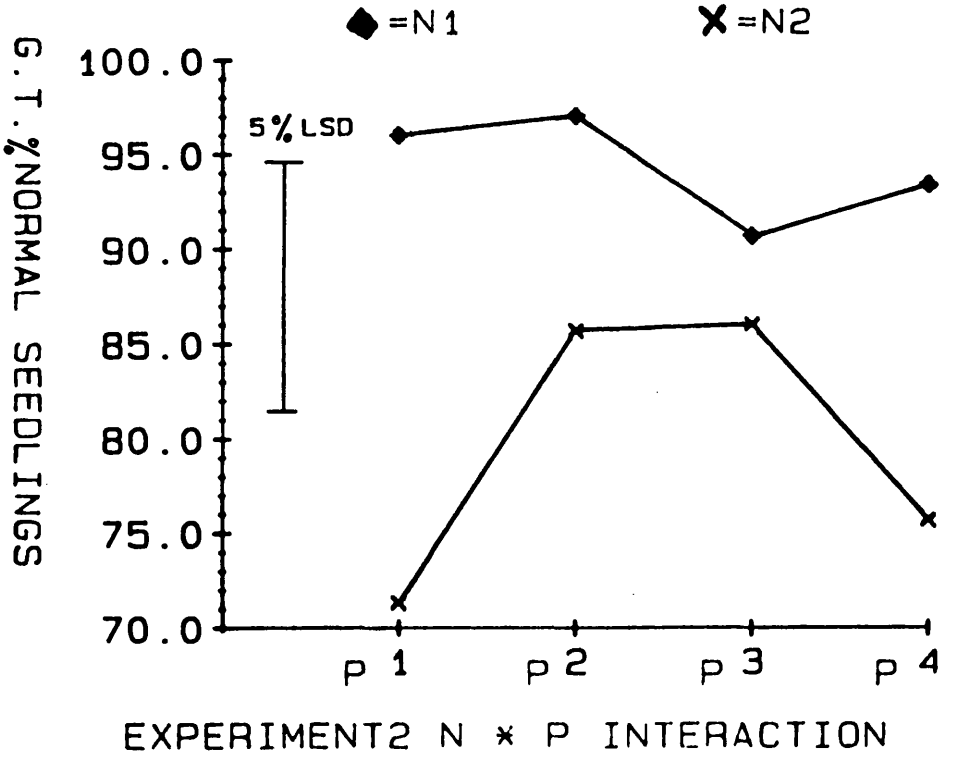

Figure 148. The effect of NP interaction on the percentage of normal seedlings on completion of the germination test.

Total nutrient levels (mg per plant)	% normal seedlings	Total nutrient levels (mg per plant)	% normal seedlings
N_1 = 100	94.25	P_1 = 25	83.67
N_2 = 1000	79.67	P_2 = 250	91.33
		P_3 = 500	88.33
		P_4 = 1000	84.50

Significance levels:

N:	0.1%	P: N.S.	N x P: N.S.
5% LSD	N: 6.59	P: 8.08	N x P: 13.19

Table 75. The effect of N and P nutrition levels on the percentage of the normal seedlings on completion of the germination test in Experiment 2.

4.4.4.3 Experiment 3: Seedling evaluation; percentage of normal seedlings

The percentage of normal seedlings after the final count of the germination test was determined in each treatment in order to examine the effect of N, P and K nutrition levels on seed vigour as determined by the seedling evaluation. From the analysis of variance presented in Table 76, it can be seen that N, P, K and their interactions had no significant effect on the percentage of normal seedlings in this experiment.

Figure 149 shows the main effect of N, P and K on the percentage of normal seedlings at the end of the germination test.

Total nutrient levels (kg per ha)	% normal seed-lings	Total nutrient levels (kg per ha)	% normal seed-lings	Total nutrient levels (kg per ha)	% normal seed-lings
N_1 = 0	87.08	P_1 = 0	86.24	K_1 = 0	86.36
N_2 = 25	85.47	P_2 = 50	87.66	K_2 = 25	85.56
N_3 = 75	86.99	P_3 = 150	85.64	K_3 = 75	87.62

Significance levels:

N: N.S. N x P: N.S.

P: N.S. N x K: N.S. N x P x K: NS

K: N.S. P x K: N.S.

L.S.D. 5%
(N,P,K) = 4.15 (NxP,PxK,NxK) = 7.19 (N x P x K) = 12.46

Table 76. The effect of N, P and K nutrition levels on the percentage normal seedlings on completion of the germination test in Experiment 3.

Figure 150 shows the effect of N and P interaction on the percentage of normal seedlings on completion of the germination test.

4.4.4.4 Experiment 4: Seedling evaluation; Percentage normal seedlings

The percentage of normal seedlings after the final count of the germination test was recorded in order to examine the effect of N and K nutrition levels on seed vigour as determined by the seedling evaluation. From the analysis of variance presented in Table 77, it can be seen that only levels of K nutrition significantly affected the

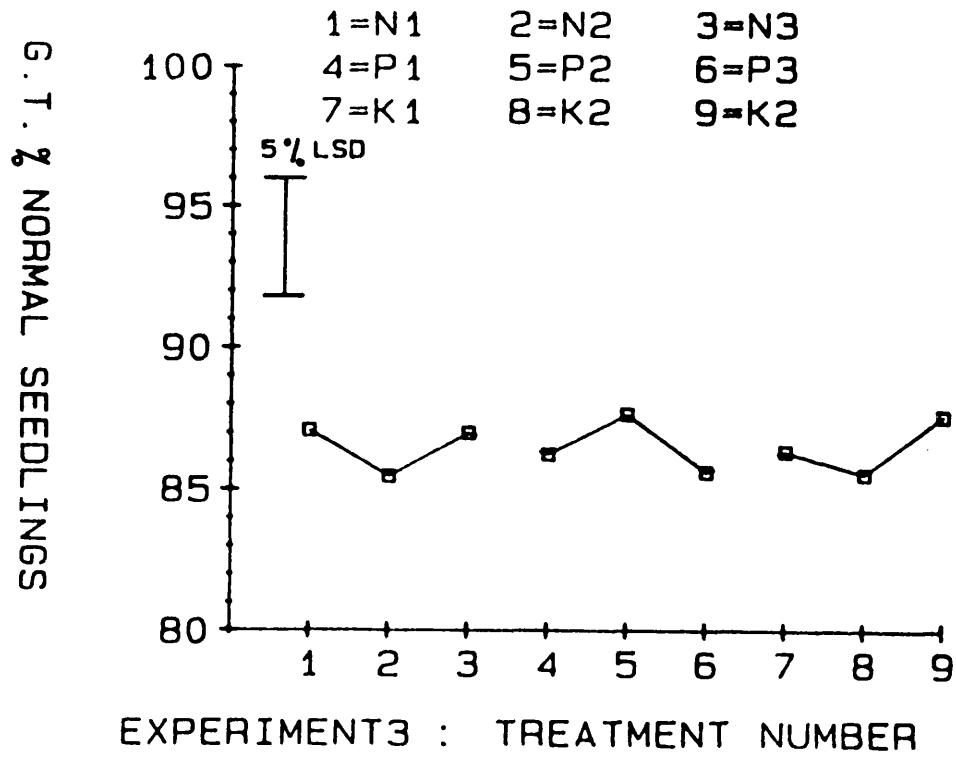

Figure 149. The main effect of N, P and K mineral nutrition levels on the percentage of normal seedlings on completion of the germination test.

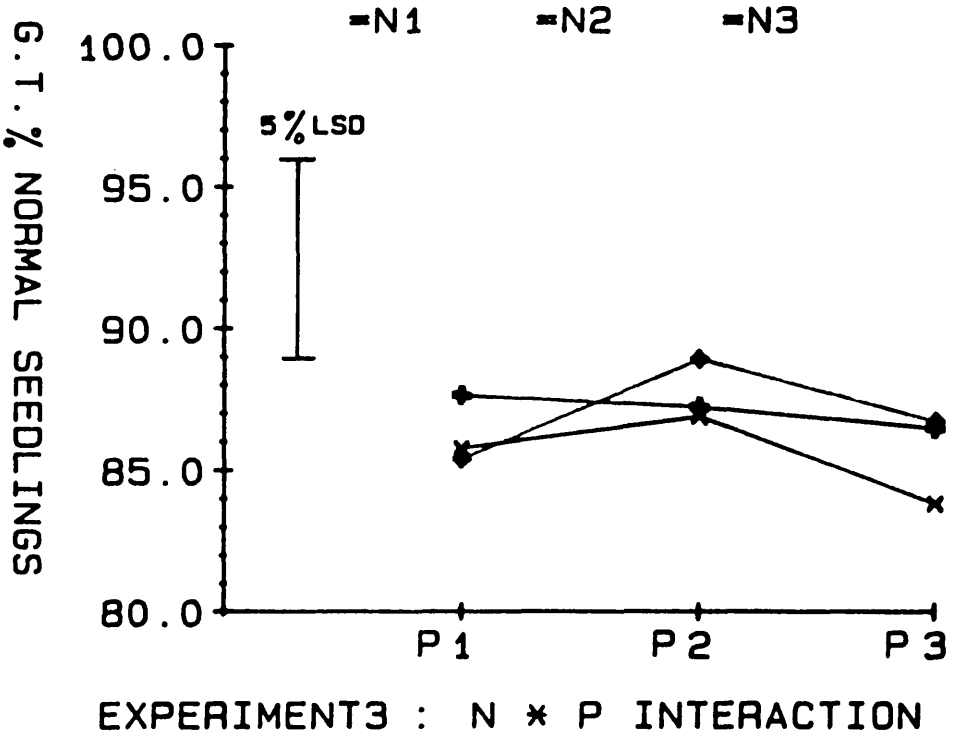

Figure 150. The effect of N and P interaction on the percentage of normal seedlings on completion of the germination test.

Total nutrient levels (mg per plant)	% normal seedlings	Total nutrient levels (mg per plant)	% normal seedlings
N_1 = 0	94.00	K_1 = 0	88.33
N_2 = 100	93.33	K_2 = 50	93.00
N_3 = 500	91.17	K_3 = 250	96.50
N_4 = 1000	93.50	K_4 = 500	94.17

Significance levels:

N: N.S. K: 1.0%, and their interaction Nx K: N.S.

5% LSD = 4.00

Table 77. The effect of N and K nutrition levels on the normal seedlings on completion of the germination test in Experiment 4.

percentage of normal seedlings in the germination test. There is no significant effect due to either N nor the N and K interaction on the percentage of the normal seedlings during the germination test.

As shown in Figure 151, the percentage of the normal seedlings increased with increasing levels of K up to K_3 and decreased at the fourth level of K in the order of $K_1 < K_2 < K_3 > K_4$, in this experiment.

Figure 152 shows the effect of NK interaction on the percnetage of normal seedlings in the germination test.

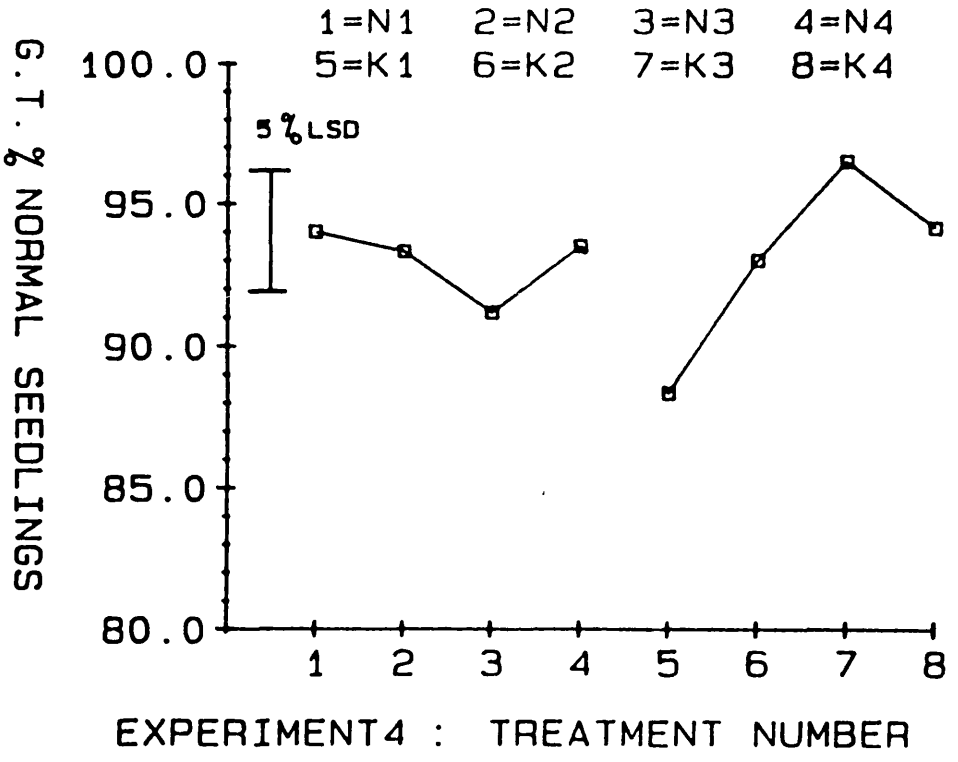

Figure 151. The main effect of N and K mineral nutrition levels on the percentage of normal seedlings on completion of the germination test.

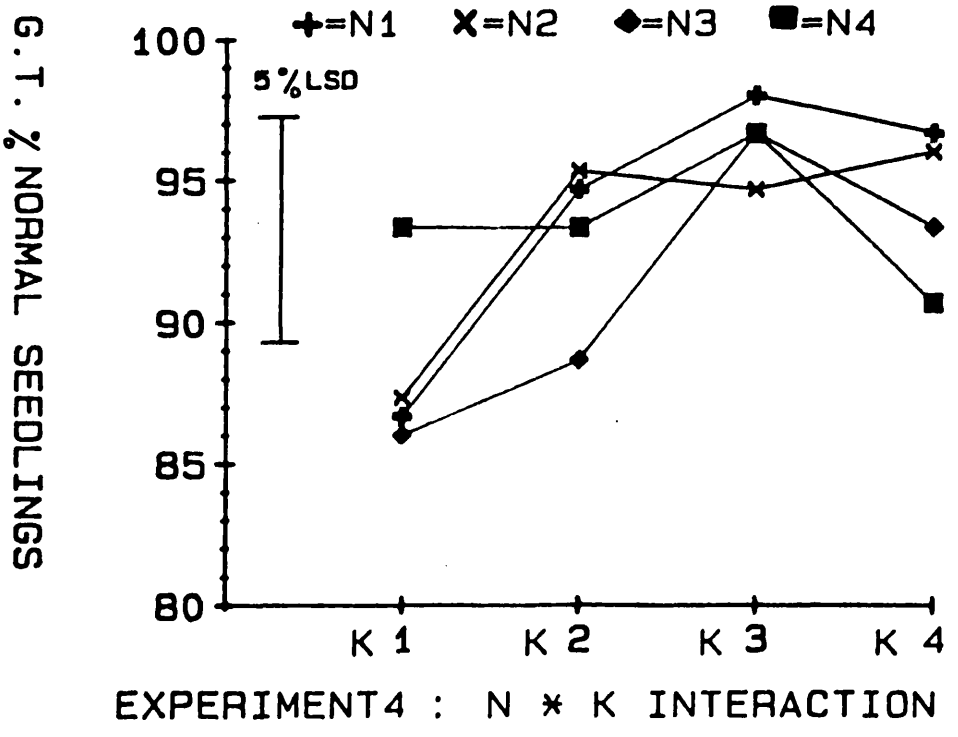

Figure 152. The effect of N and K interaction on the percentage of normal seedlings on completion of the germination test.

4.4.5.1 Experiment 1: Seed leachate conductivity (μs per g)

The seed leachate conductivity from samples of seeds in each treatment was determined in order to examine the effect of N, P and K nutrition on seed vigour as determined by the conductivity test.

Total nutrient levels (mg per plant)	Conductivity (μs per g)	Total nutrient levels (mg per plant)	Conductivity (μs per g)	Total nutrient levels (mg per plant)	Conductivity (μs per g)
N_1 = 100	10.18	P_1 = 50	13.85	K_1 = 40	12.05
N_2 = 150	11.08	P_2 = 70	12.06	K_2 = 60	10.39
N_3 = 300	9.02	P_3 = 140	8.67	K_3 = 120	9.41
N_4 = 500	11.65	P_4 =210	7.35	K_4 = 180	10.08

Significance levels:

N: 0.1%	N x P: 0.1%	
P: 0.1%	N x K: 0.1%	N x P x K: 0.1%
K: 0.1%	P x K: 0.1%	
L.S.D. (N,P,K) = 0.196	(NxP,PxK,NxK) = 0.392	(N x P x K) = 0.784

Table 78. The effect of N, P and K mineral nutrition on seed conductivity in Experiment 1.

From the analysis of variance presented in Table 78, it can be seen that levels of N, P, K and the interaction NP, NK, PK and NPK significantly affected the seed leachate conductivity at the 0.1% significance level.

As is shown in Figure 153, the seed leachate conductivity is decreased by increasing levels of P and also by increasing levels of K

up to K_3 which then slightly increases from K_3 to K_4, whereas the effect of N levels is small, but significant in this experiment and in the orders of $N_4 > N_2 > N_1 > N_3$, $P_1 > P_2 > P_3 > P_4$, and $K_1 > K_2 > K_4 > K_3$.

Figures 154, 155 and 156 show the effects of NP, PK and NK interaction on the seed leachate conductivity. The highest and lowest seed leachate conductivities were achieved in the interactions NP by N_4P_1 (15.64 µs per g) and N_3P_4 (6.58 µs per g) and in the interaction PK by P_1K_1 (15.09 µs per g) and P_4K_3 (5.98 µs per g) and in the interaction NK by N_4K_2 (14.23 µs per g) and N_3K_4 (8.08 µs per g). In the interaction NPK the highest seed leachate conductivity was achieved by the combination $N_4P_2K_1$ (19.55 µs per g) and the lowest by $N_3P_4K_3$ (4.70 µs per g).

4.4.5.2 Experiment 2: Seed leachate conductivity (µs per g)

The seed leachate conductivity from seed samples in each treatment was determined in order to examine the effect of N and P nutrition on seed vigour as determined by the conductivity test. From the analysis of variance presented in Table 79 it can be seen that levels of N, P and their interaction NP significantly affected the seed leachate conductivity at 0.1%, 5.0% and 0.1% significance levels respectively.

As shown in Figure 157 seed leachate conductivity increased with increasing levels of N and decreased with increasing levels of P significantly, initially, ie. P_1 to P_2 and slowly rising from P_2 to P_4 in this experiment in the orders of $N_2 > N_1$ and $P_1 > P_4 > P_3 > P_2$.

Figure 158 shows the effect of N and P interaction on the seed leachate conductivity. The highest conductivity was achieved with the

combination N_2P_1 (56.94 µs per g) and the lowest by N_1P_1 (20.91 µs per gram).

Total nutrient levels (mg per plant)	Conductivity (µs per g)	Total nutrient levels (mg per plant)	Conductivity (µs per g)
N_1 = 100	24.42	P_1 = 25	38.93
N_2 = 1000	43.79	P_2 = 250	30.84
		P_3 = 500	31.21
		P_4 = 1000	35.45

Significance levels:

N:	0.1%	P: 5.0%	N x P: 0.1%
5% LSD	N: 3.81	P: 5.38	N x P: 7.62

Table 79. The effect of N and P nutrition levels on seed leachate conductivity in Experiment 2.

4.4.5.3 Experiment 3: Seed leachate conductivity (µs per g)

The seed leachate conductivity from seed samples in each treatment was determined in order to examine the effect of N, P and K nutrition on seed vigour as determined by the conductivity test. From the analysis of variance presented in Table 80, it can be seen that only levels of N and the N x P interaction significantly affected the seed leachate conductivity at the 0.1% and 5.0% levels respectively in this experiment.

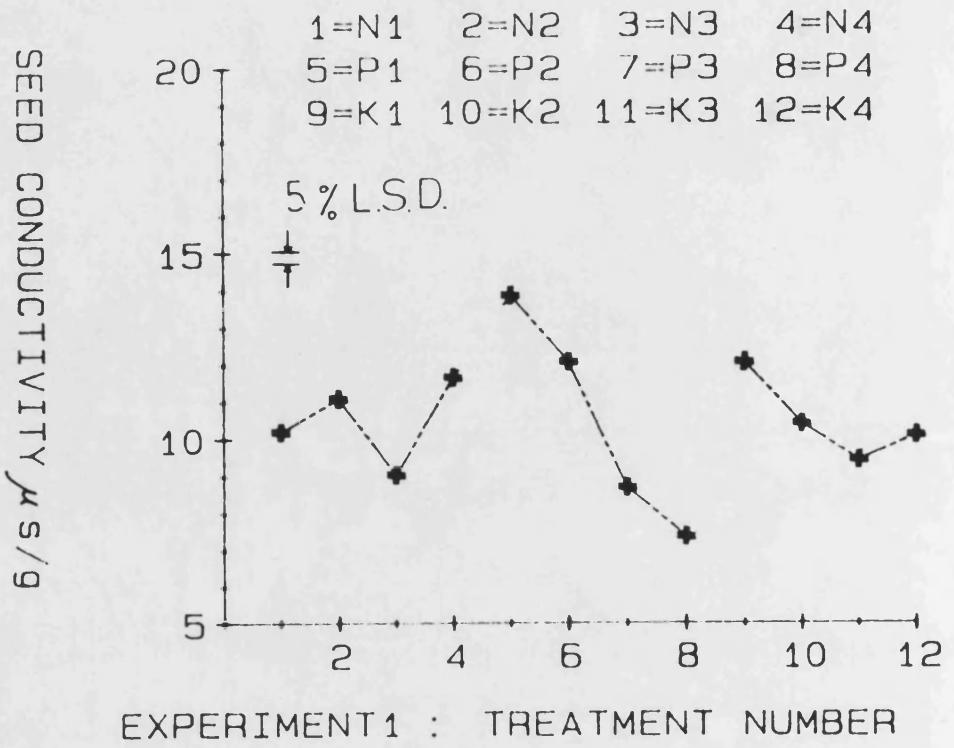

Figure 153. The main effect of N, P and K mineral nutrition levels on seed vigour as determined by the seed leachate's conductivity in µs per g of air dried seeds.

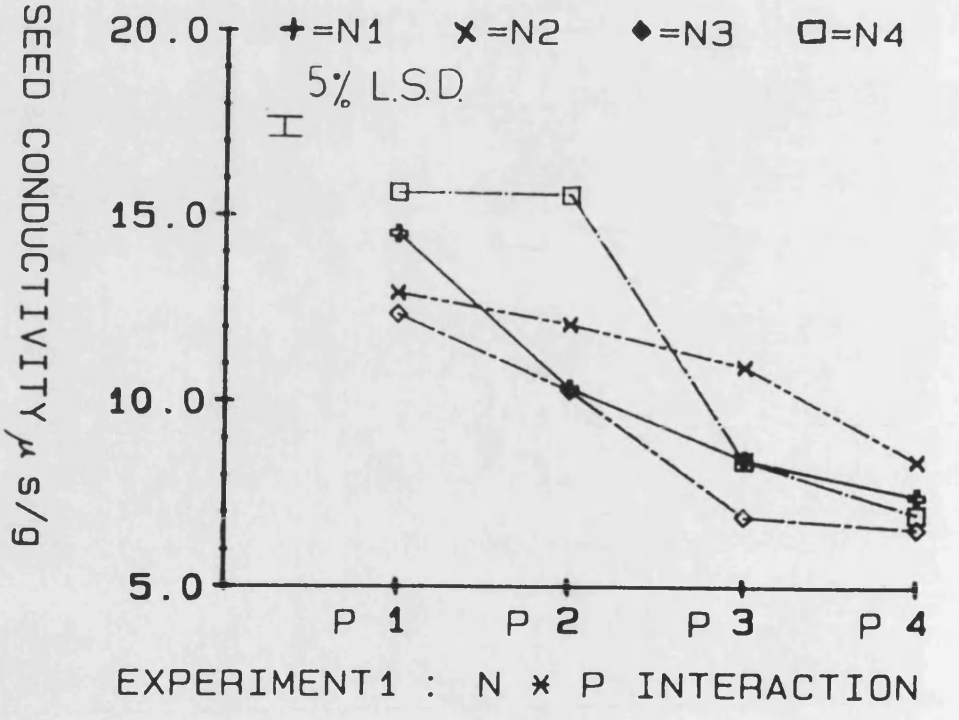

Figure 154. The effect of N and P interaction on the seed leachate conductivity in µs per g of air dried seeds.

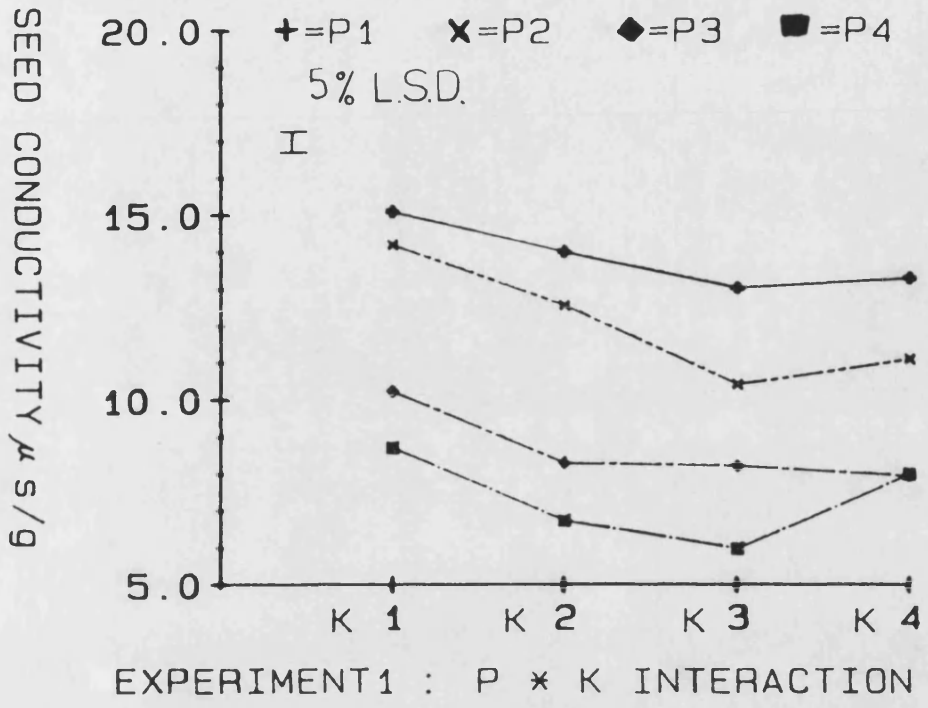

Figure 155. The effect of P and K interaction on the seed leachate conductivity in µs per g of air dried seeds.

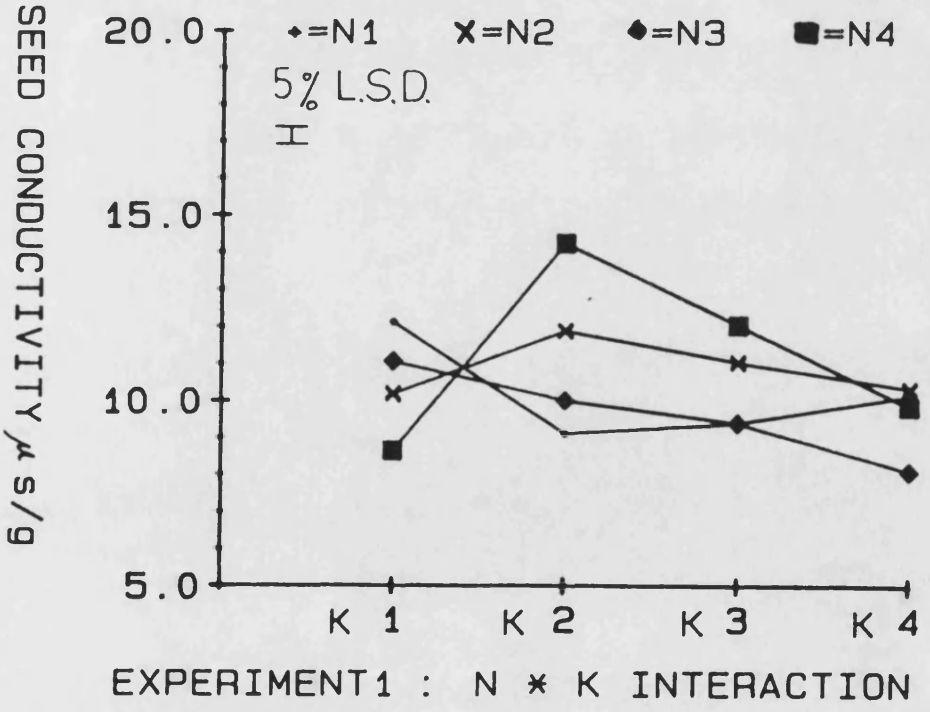

Figure 156. The effect of N and K interaction on the seed leachate conductivity in µs per g of air dried seeds.

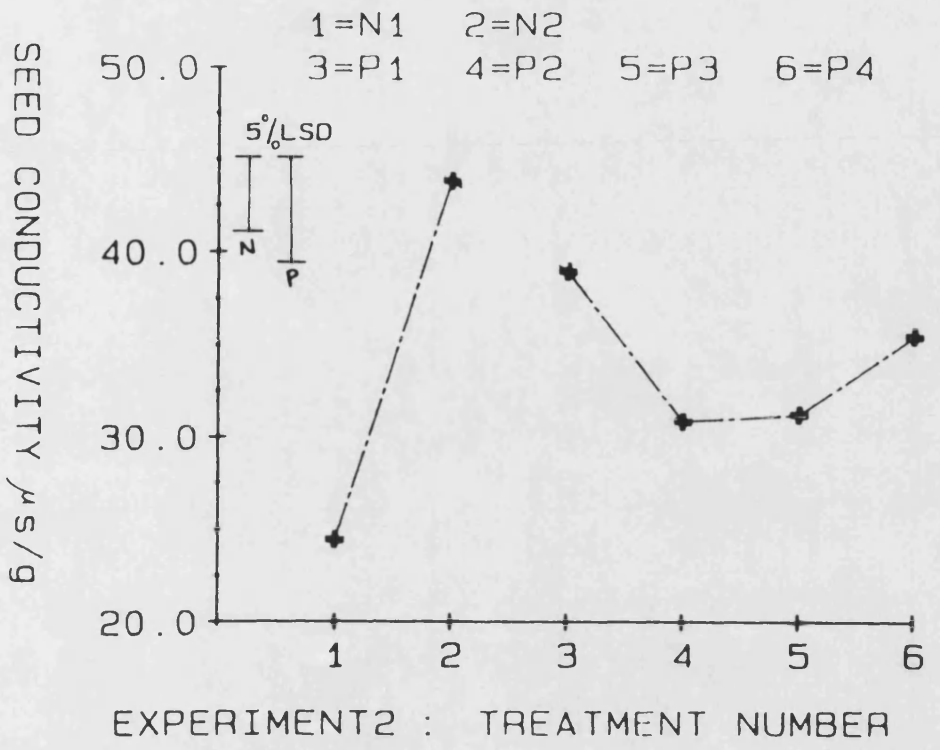

Figure 157. The main effect of N and P mineral nutrition on the seed vigour as determined by the conductivity of seed leachates in µs per g of air dried seeds.

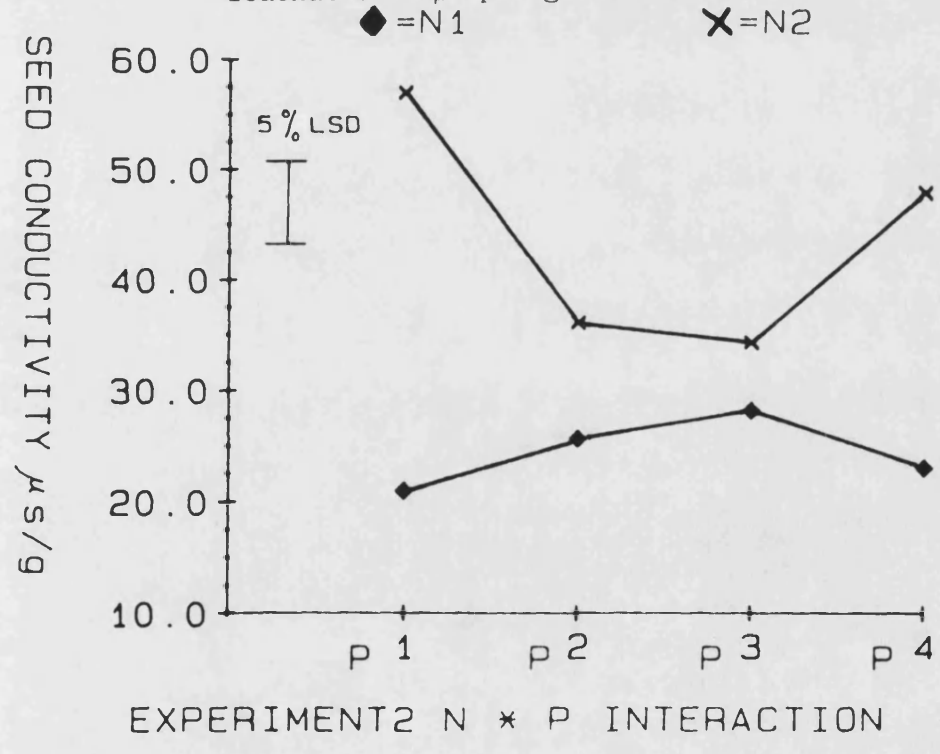

Figure 158. The effect of N and P interaction on the seed leachate conductivity in µs per g of air dried seeds.

Total nutrient levels (kg per ha)	Conduct-ivity (µs per g)	Total nutrient levels (kg per ha)	Conduct-ivity (µs per g)	Total nutrient levels (kg per ha)	Conduct-ivity (µs per g)
N_1 = 0	22.64	P_1 = 0	21.10	K_1 = 0	19.96
N_2 = 25	21.62	P_2 = 50	20.37	K_2 = 25	20.78
N_3 = 75	18.31	P_3 = 150	21.09	K_3 = 75	21.83

Significance levels:

N: 0.1% N x P: 5.0%

P: N.S. N x K: N.S. N x P x K: N.S.

K: N.S. P x K: N.S.

L.S.D. 5%
(N,P,K) = 2.24 (NxP,PxK,NxK) = 3.87 (N x P x K) = 6.71

Table 80. The effect of N, P and K mineral nutrition on seed leachate conductivity in Experiment 3.

As shown in Figure 159, seed conductivity decreased with increasing levels of N in the order of $N_1 > N_2 > N_3$.

Figure 160 shows the effect of N x P interaction on seed leachate conductivity. The highest seed conductivity was achieved by the combination N_1P_3 (25.65 µs per g) and the lowest by N_3P_1 (17.63 µs per g).

4.4.5.4 Experiment 4: Seed leachate conductivity (µs per g)

The seed leachate conductivity from seed samples in each treatment was determined in order to examine the effect of N and K nutrition on seed vigour as determined by the conductivity test. From the analysis of variance presented in Table 81, it can be seen that

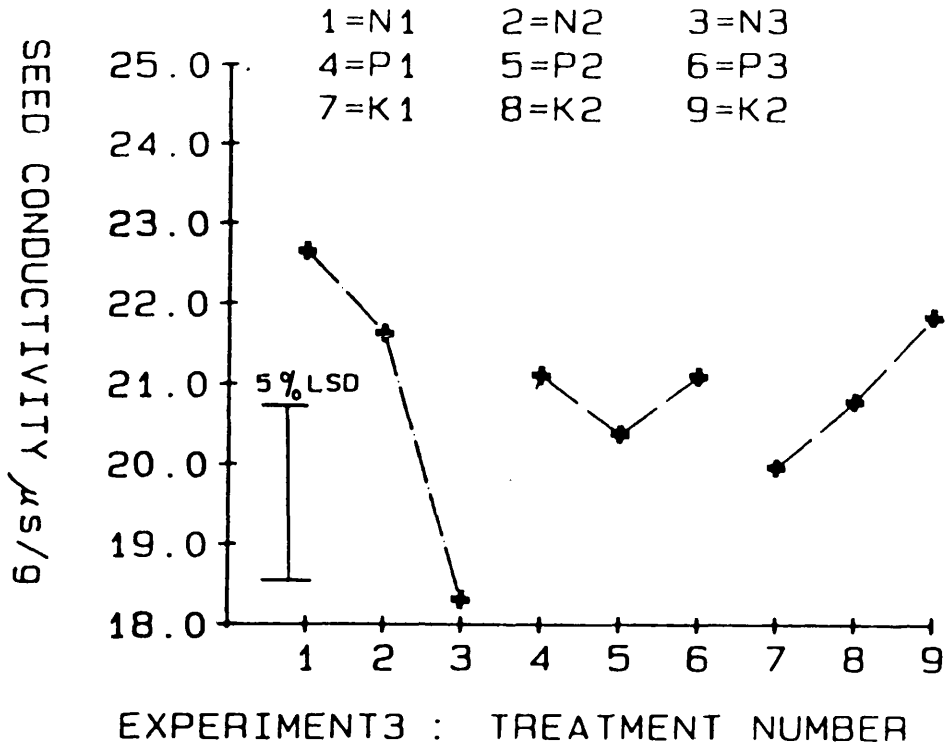

Figure 159. The main effect of N, P and K mineral nutrition levels on seed vigour as determined by the conductivity of seed leachates in µs per g of air dried seeds.

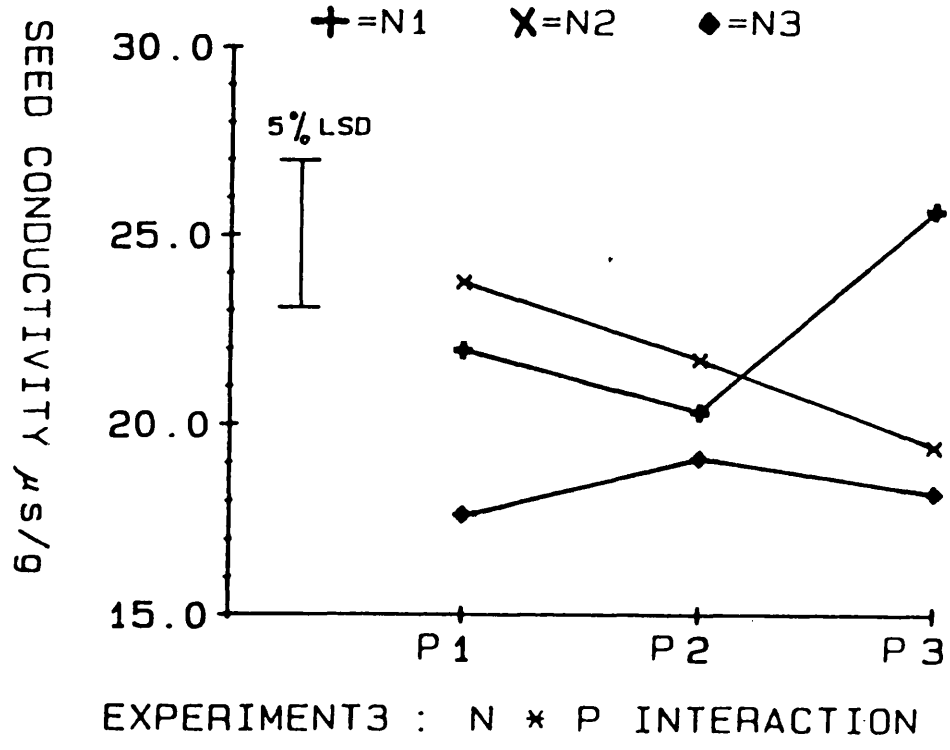

Figure 160. The effect of N x P interaction on the seed leachates conductivity in µs per g of air dried seeds.

Total nutrient levels (mg per plant)	Conductivity (μs per g)	Total nutrient levels (mg per plant)	Conductivity (μs per g)
N_1 = 0	24.18	K_1 = 0	22.00
N_2 = 100	22.34	K_2 = 50	19.80
N_3 = 500	17.85	K_3 = 250	19.57
N_4 = 1000	15.75	K_4 = 500	18.76

Significance levels:

N: 0.1% K: N.S., and their interaction Nx K: N.S.

5% LSD = 3.40

Table 81. The effect of N and K nutrition levels on seed leachate conductivity in Experiment 4.

only levels of N nutrition significantly affected the seed leachate conductivity at the 0.1% level. There is no significant effect by either K levels or the N and K interaction on seed leachate conductivity.

As shown in Figure 161 seed leachate conductivity decreased with increasing levels of nitrogen in the order of $N_1 > N_2 > N_3 > N_4$ in this experiment. Figure 162 shows the effect of NK interaction on seed leachate conductivity.

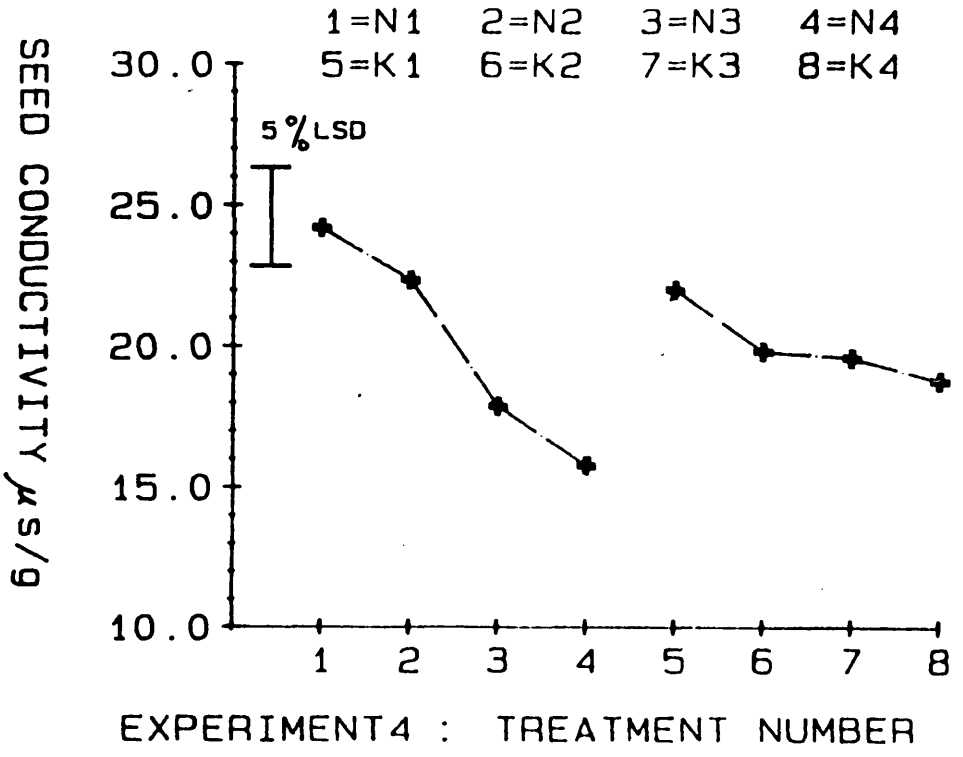

Figure 161. The main effect of N and K nutrition levels on seed vigour as determined by the conductivity of seed leachates in µ s per g of air dried seed.

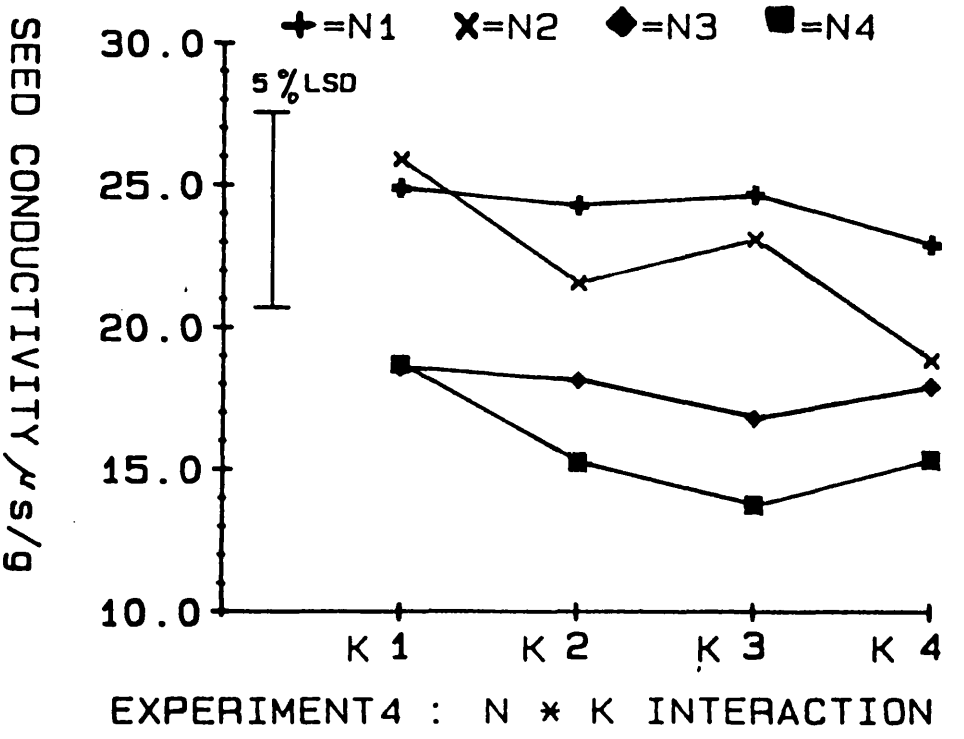

Figure 162. The effect of N K interaction on the seed leachates conductivity in µs per g of air dried seeds.

4.4.6.1 Experiment 1: Cold Test: Percentage germination

The percentage germination of the seeds during the cold test was recorded in order to examine the effect of N, P and K nutrition levels on seed vigour as determined by the cold test. From the

Total nutrient levels (mg per plant)	% Germination	Total nutrient levels (mg per plant)	% germination	Total nutrient levels (mg per plant)	% germination
N_1 = 0	95.75	P_1 = 0	96.94	K_1 = 0	95.75
N_2 = 150	97.13	P_2 = 70	97.88	K_2 = 60	97.38
N_3 = 300	97.38	P_3 = 140	96.63	K_3 = 120	97.94
N_4 = 500	97.94	P_4 =210	97.75	K_4 = 180	97.13

Significance levels:

N: 1.0% N x P: 0.1%

P: N.S. N x K: 0.1% N x P x K: 0.1%

K: 1.0% P x K: 0.1%

L.S.D. (N,P,K) = 1.16 (NxP,PxK,NxK) = 2.33 (N x P x K) = 4.66

Table 82. The effect of N, P and K mineral nutrition levels on the percentage germination during the cold test in Experiment 1.

analysis of variance presented in Table 82, it can be seen that the levels of N, K and the interactions NP, NK, PK and NPK significantly affected the percentage germination during the cold test at the 1.0% significance level for the first two and 0.1% significance level for the remaining four.

As shown in Figure 163 the percentage germination increased with increasing levels of N and K only with slight decrease from K_3 to K_4 and decreased by increasing levels of P after an initial increase but not significantly in this experiment, and in the orders of $N_4 > N_3 > N_2 > N_1$, $P_2 > P_1 > P_4 > P_3$ and $K_3 > K_2 > K_4 > K_1$.

Figures 164, 165 and 166 show the effects of NP, NK and PK interactions on the percentage germination in the cold test. The highest and the lowest percentage germinations by the interactions NP, NK and PK were by combinations N_1P_2, N_3P_2 and N_4P_4 (99.0%) and N_1P_4 (94.0%), N_1K_3, N_2K_2 (99.5%) and N_1K_1 (92.5%) and P_3K_2 (99.5% and P_3K_1 (91.5%).

4.4.6.2 Experiment 2: Cold Test: Percentage Germination

The germination percentage of the seeds during the cold test was recorded in order to examine the effect of N and P nutrition on seed vigour as determined by the cold test. From the analysis of

Total nutrient levels (mg per plant)	% Germination	Total nutrient levels (mg per plant)	% Germination
N_1 = 100	95.50	P_1 = 25	83.00
N_2 = 1000	81.00	P_2 = 250	91.00
		P_3 = 500	94.00
		P_4 = 1000	85.00

Significance levels:

N:	5%	P: N.S.	N x P: N.S.
5% LSD	N: 11.51	P: 16.27	N x P: 23.07

Table 83. The effect of N and P nutrition levels on the percentage of germination in the cold test in Experiment 2.

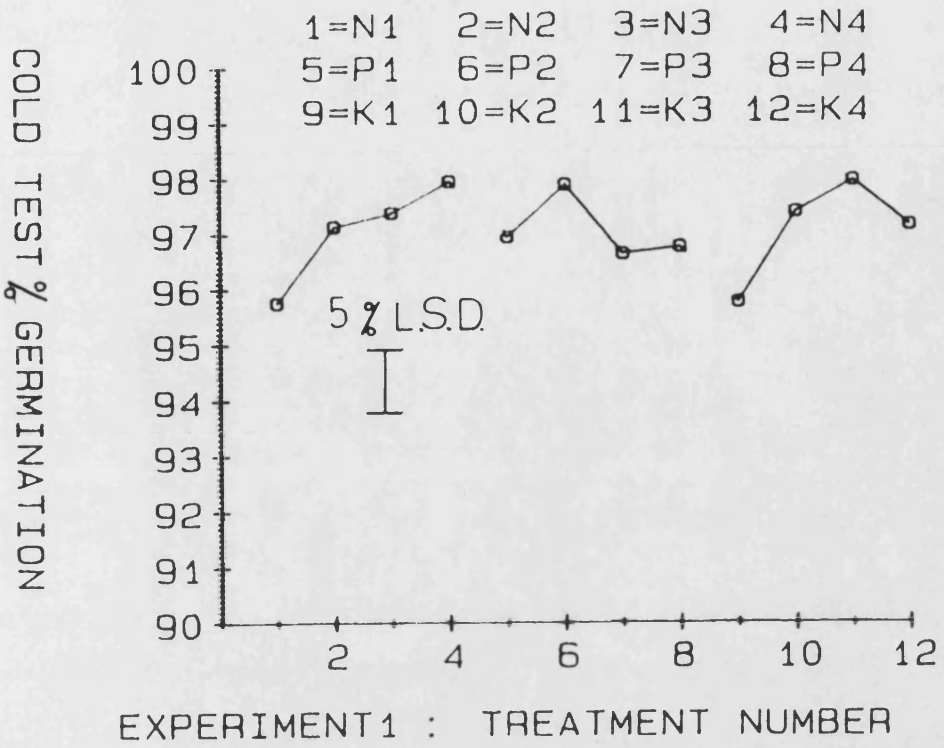

Figure 163. The main effect of N, P and K mineral nutrition levels on seed vigour as determined by the percentage germination during the cold test.

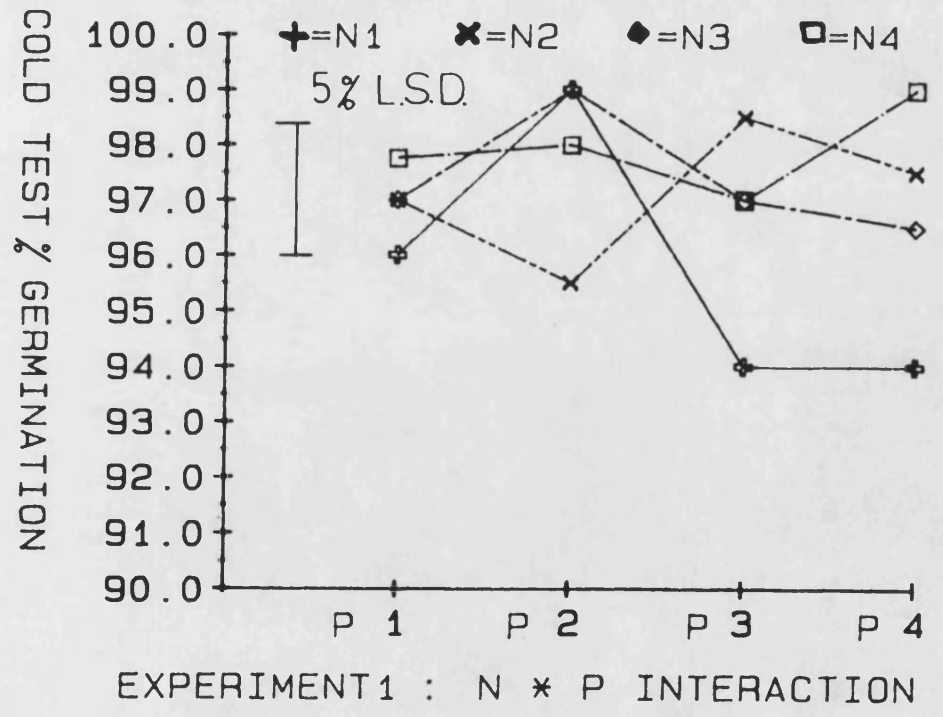

Figure 164. The effect of N and P interaction on the percentage germination during the cold test.

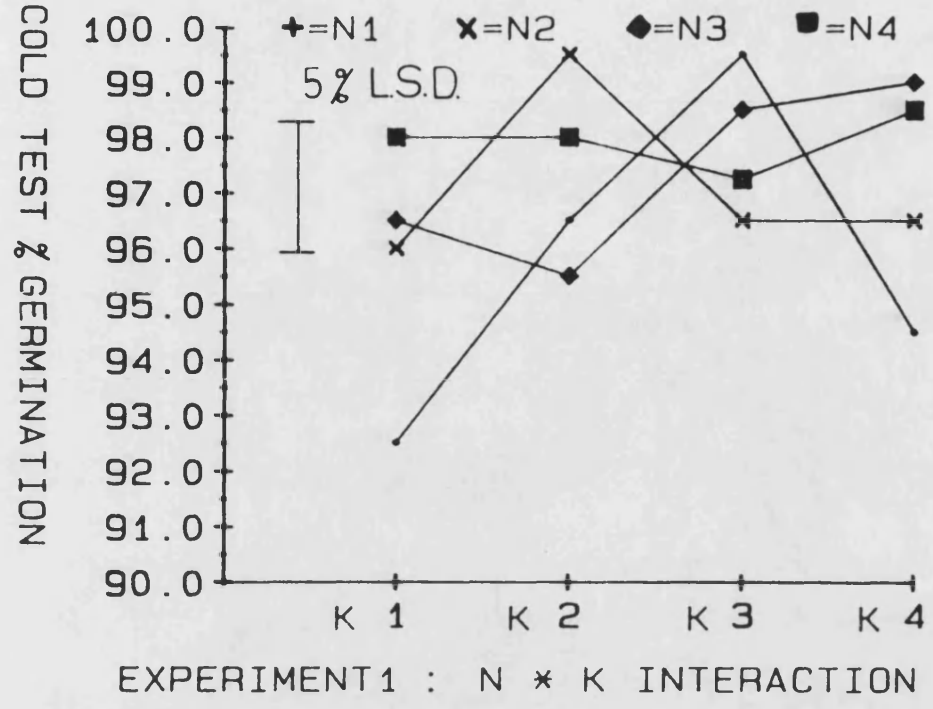

Figure 165. The effect of N and K interaction on the percentage germination during the cold test.

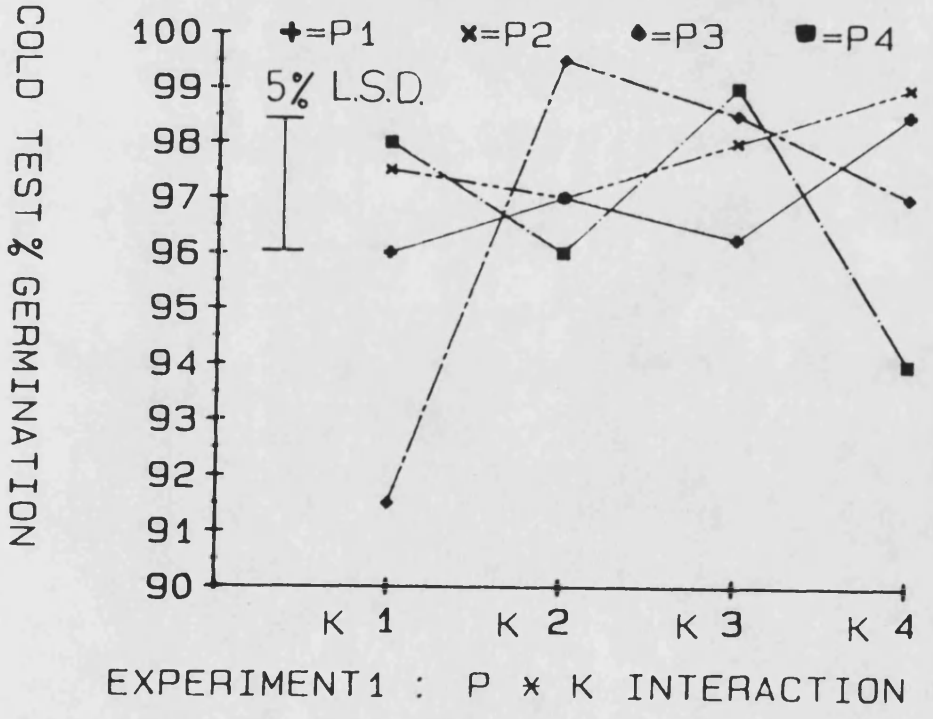

Figure 166. The effect of P and K interaction on the percentage germination during the cold test.

variance presented in Table 83, it can be seen that only levels of N significantly affected the germination percentage at only 5.0% significance level.

As shown in Figure 167, the percentage germination decreased with increasing N levels and that increased with increasing levels of P up to P_3 when it declined sharply from P_3 to P_4 but not significantly in this experiment and in the order of $N_1 > N_2$ and $P_3 > P_2 > P_4 > P_1$.

Figure 168 shows the effect of NP interaction on the percentage germination during the cold test.

4.4.6.3 Experiment 3: Cold test: Percentage Germination

The percentage germination of the seeds at the end of the cold test was recorded for each treatment in order to examine the effect of N, P and K nutrition levels of seed vigour as determined by the cold test. From the analysis of variance presented in Table 84, it can be seen that the percentage germination was significantly affected by the levels of N and K at 0.1% and 5.0% and also by the interactions N x P and N x P x K at the 1.0% and 0.1% levels respectively.

As shown in Figure 169 the percentage germination decreases with increasing N levels in the following order: $N_1 > N_2 > N_3$ and shown in the order of $P_1 < P_2 \simeq P_3$.

Figure 170 shows the effect of N and P interaction on the percentage germination. The highest germination was achieved by the combination N_1P_2 (69.30%) and the lowest by N_3P_1 (36.60%).

In the three way interaction (N x P x K), the highest percentage germination was achieved by the combination $N_1P_2K_2$ (76.3%) and the lowest by $N_2P_2K_2$ (22.3%) in this experiment.

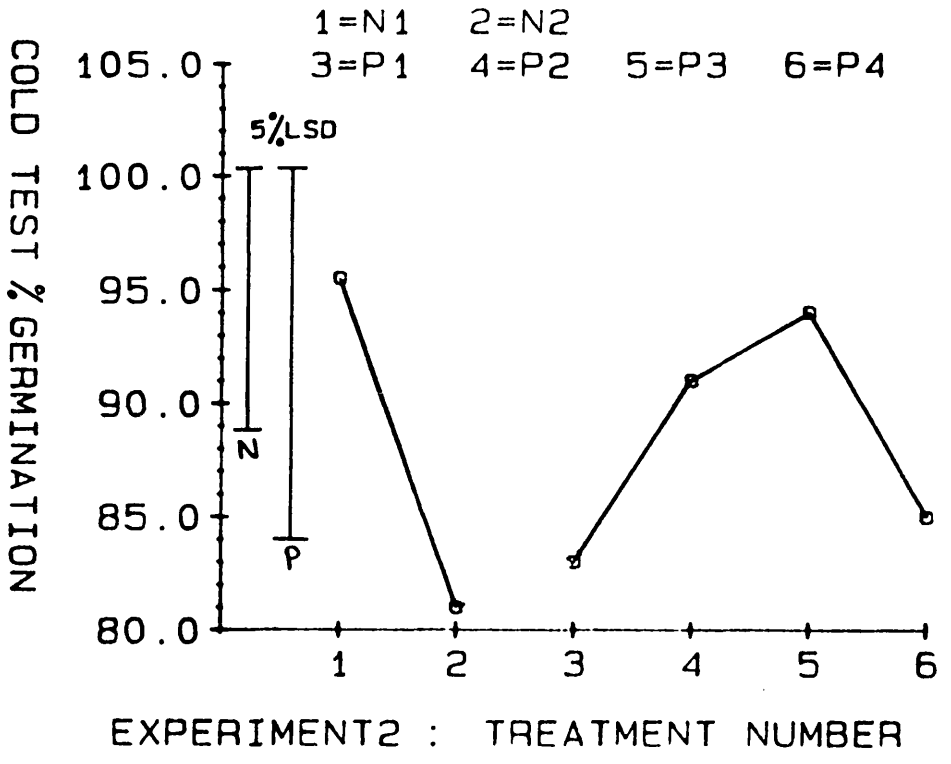

Figure 167. The main effect of N and P mineral nutrition levels on seed vigour as determined by the percentage germination during the cold test.

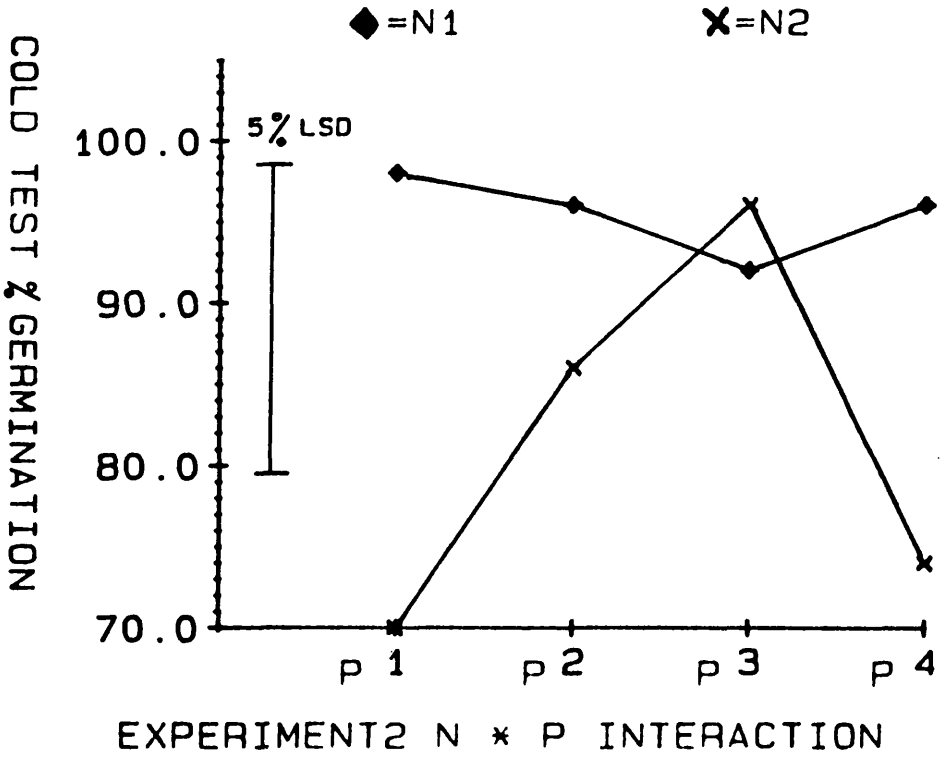

Figure 168. The effect of NP interaction on the percentage germination during the cold test.

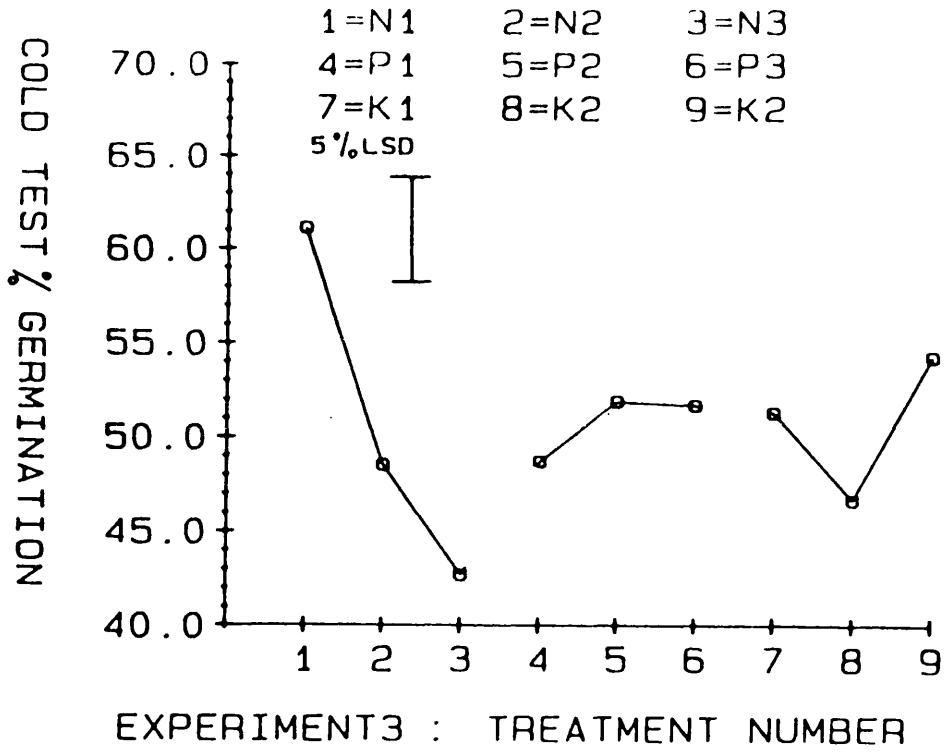

Figure 169. The main effect of N, P and K mineral nutrition levels on percentage germination during the cold test.

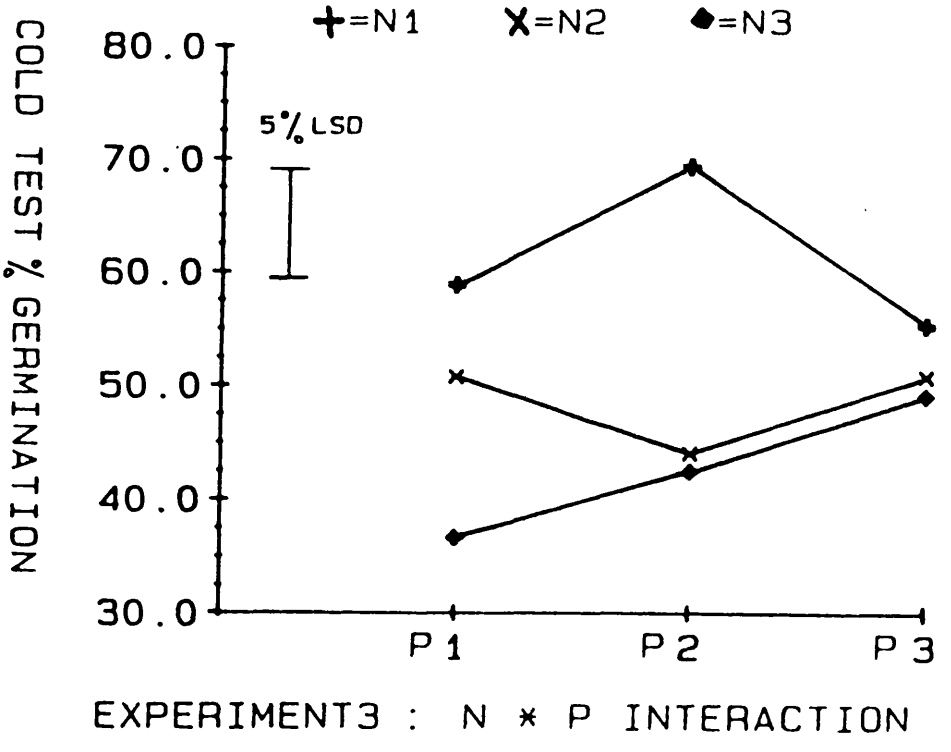

Figure 170. The effect of N x P interaction on percentage germination during the cold test.

Total Nutrient levels (kg per ha)	% Germination	Total nutrient levels (kg per ha)	% Germination	Total nutrient levels (kg per ha)	% Germination
N_1 = 0	61.1	P_1 = 0	48.7	K_1 = 0	51.3
N_2 = 25	48.5	P_2 = 50	51.9	K_2 = 25	46.7
N_3 = 75	42.7	P_3 = 150	51.7	K_3 = 75	54.3

Significance levels:

N: 0.1% N x P: 1.0%

P: N.S. N x K: N.S. N x P x K: 0.1%

K: 5% P x K: N.S.

L.S.D. 5%
(N,P,K) = 5.55 (NxP,PxK,NxK) = 9.62 (N x P x K) = 16.66

Table 84. The effect of N, P and K mineral nutrition levels on the percentage of germination in the cold test in Experiment 3.

4.4.6.4 Experiment 4: Cold test: Percentage Germination

The germination percentage of the seeds during the cold test was recorded in order to examine the effect of N and K nutrition levels on seed vigour as determined by the cold test. From the analysis of variance presented in Table 85, it can be seen that the percentage germination was not affected by levels of N, K or their interaction N x K.

Figure 171 shows the main effect of N and K levels on the percentage germination during the cold test in this experiment.

Figure 172 shows the effect of NK interaction on the percentage germination during the cold test.

Total nutrient levels (mg per plant)	% germination	Total nutrient levels (mg per plant)	% germination
N_1 = 0	71.5	K_1 = 0	65.9
N_2 = 100	70.2	K_2 = 50	72.0
N_3 = 500	69.7	K_3 = 250	69.1
N_4 = 1000	74.0	K_4 = 500	78.3

Significance levels:

N: N.S. K: N.S., and their interaction Nx K: N.S.

5% LSD = 10.96

Table 85. The effect of N and K nutrition levels on the percentage germination in the cold test in Experiment 4.

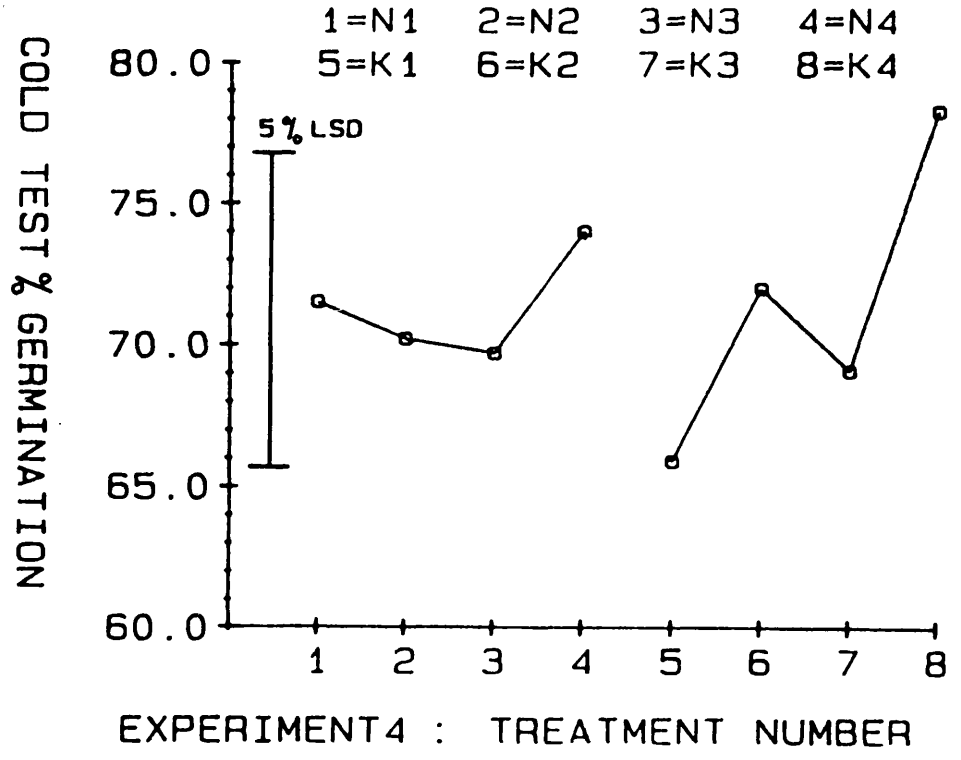

Figure 171. The main effect of N and K mineral nutrition levels on seed vigour as determined by the percentage of germination during the cold test.

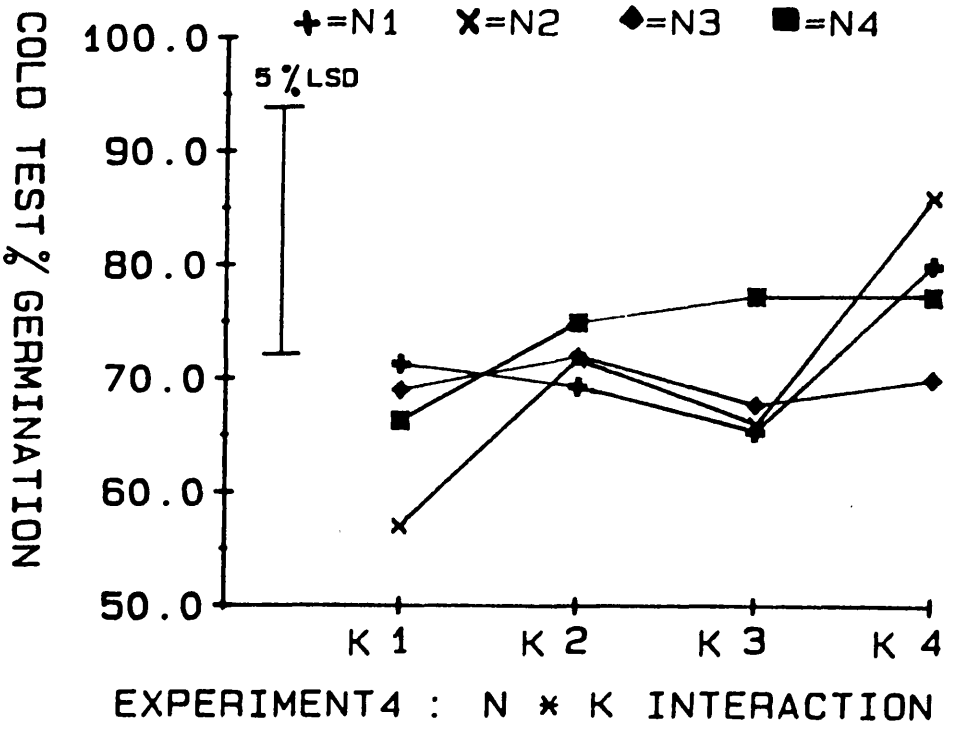

Figure 172. The effect of N K interaction on the percentage germination during the cold test.

4.4.7.1 Experiment 1: Cold test: Seedling dry weight.

The seedling dry weight of the total seedlings in the cold test was recorded after the completion of this test in order to examine the effect of N, P and K nutrition on seed vigour as determined by seedling dry weight. From the analysis of variance

Total nutrient levels (mg per plant)	Weight (g)	Total nutrient levels (mg per plant)	Weight (g)	Total nutrient levels (mg per plant)	Weight (g)
N_1 = 0	1.654	P_1 = 0	1.576	K_1 = 0	1.742
N_2 = 150	1.788	P_2 = 70	1.676	K_2 = 60	1.772
N_3 = 300	1.744	P_3 = 140	1.872	K_3 = 120	1.731
N_4 = 500	1.823	P_4 =210	1.885	K_4 = 180	1.763

Significance levels:

N: 0.1%	N x P: 0.1%	
P: 0.1%	N x K: 0.1%	N x P x K: 0.1%
K: N.S.	P x K: 0.1%	
L.S.D. (N,P,K) = 0.057	(NxP,PxK,NxK) = 0.114	(N x P x K) = 0.228

Table 86. The effect of N, P and K mineral nutrition on the seedling dry weight on completion of the cold test in Experiment 1.

presented in Table 86, it can be seen that the seedling dry weight was significantly affected by the levels of N, P and the interactions NP, NK, PK and NPK at 0.1% significance level.

As shown in Figure 173 the seedling dry weight increased with increasing levels of N and P nutrition levels in this experiment and in the orders of $N_4 > N_2 > N_3 > N_1$, $P_4 > P_3 > P_2 > P_1$ and $K_2 \approx K_4 > K_1 > K_3$.

Figures 174, 175 and 176 show the effect of NP, NK and PK interactions on the seedling dry weight. The highest and the lowest seedling dry weights in the interactions NP, NK and PK were achieved by the combinations N_4P_3 (2.02 g) and N_3P_1 (1.47 g); N_4K_4 (1.93 g) and N_1K_1 (1.50 g); and P_4K_1 (2.08 and P_1K_2 (1.49 g).

In the interaction NPK the highest seedling dry weight was achieved by the combination $N_2P_4K_1$ (2.39 g) and the lowest by $N_1P_2K_1$ (1.24 g).

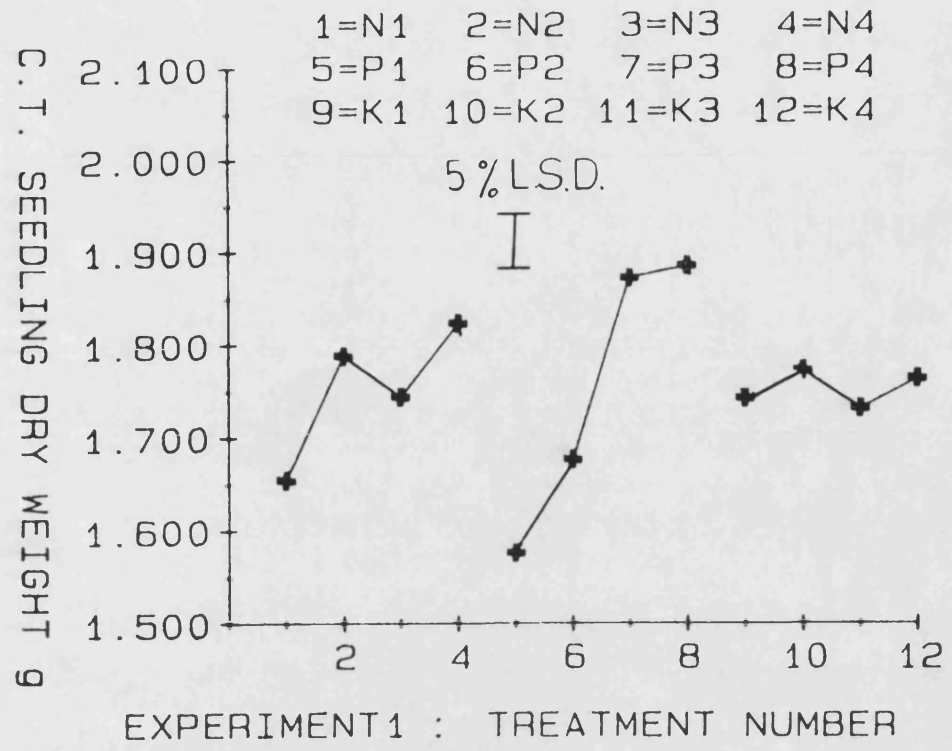

Figure 173. The main effect of N, P and K mineral nutrition levels on the seedling dry weight on completion of the cold test.

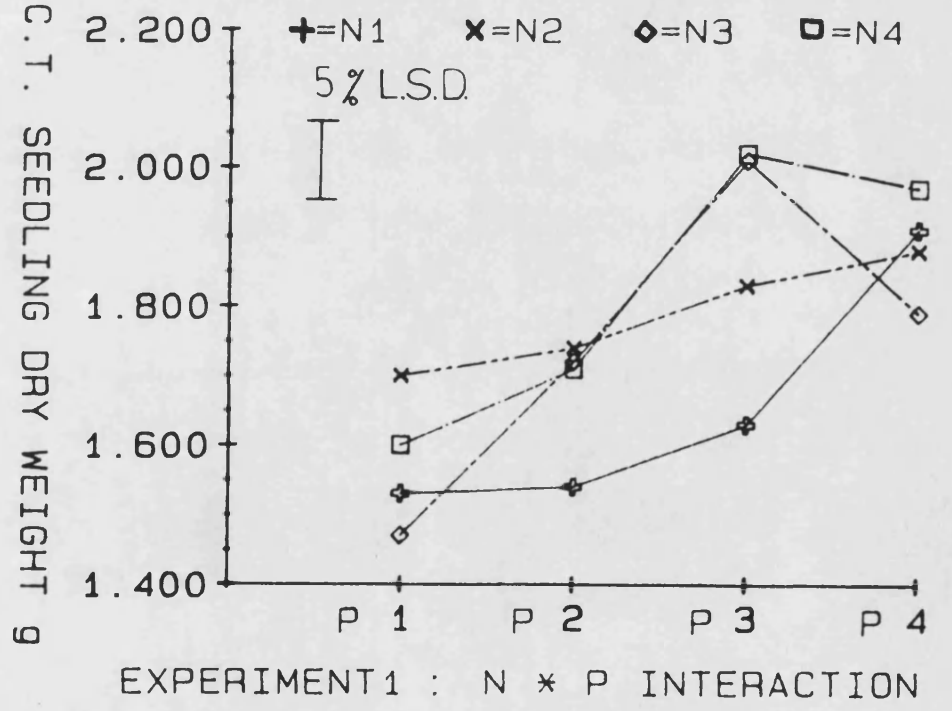

Figure 174. The effect of N and P interaction on the seedling dry weight on completion of the cold test.

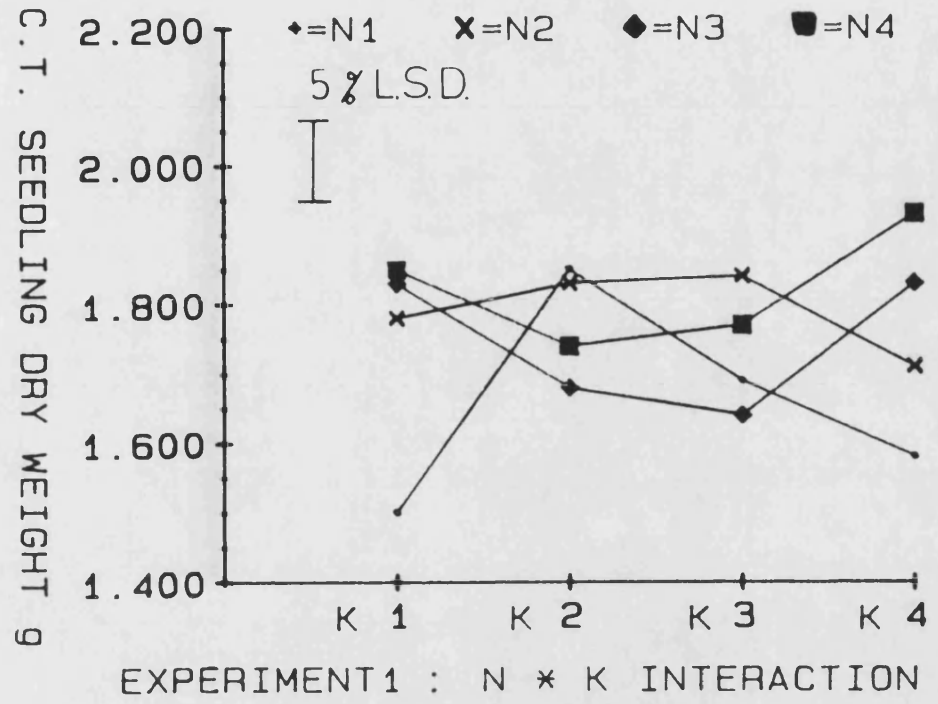

Figure 175. The effect of N and K interaction on the seedling dry weight on completion of the cold test.

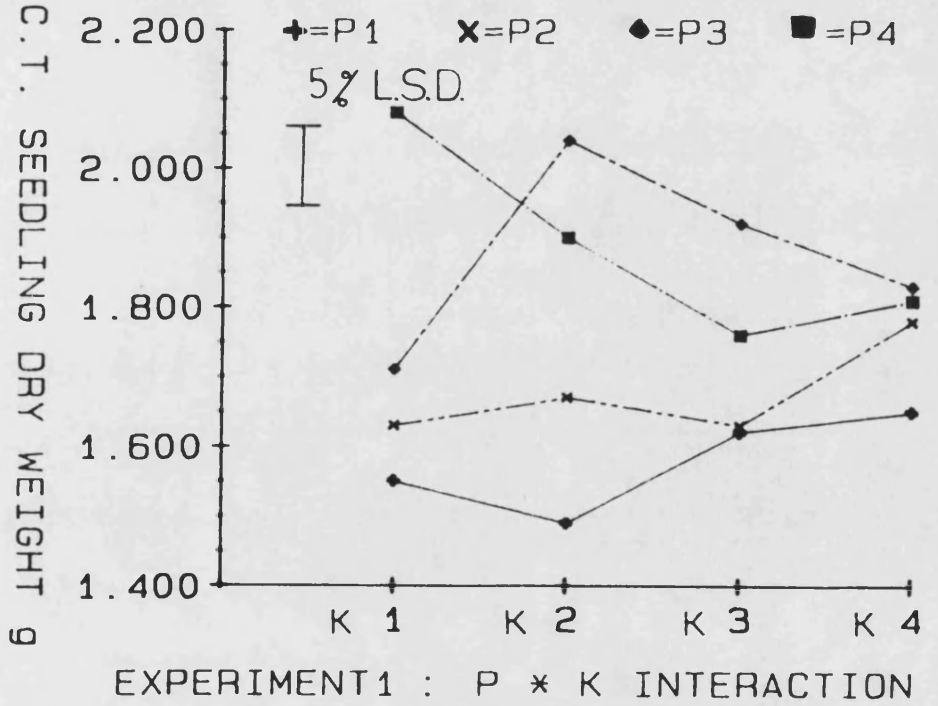

Figure 176. The effect of P and K interaction on the seedling dry weight on completion of the cold test.

4.4.7.2 Experiment 2: Cold test; Seedling dry weight

The seedling dry weight of the total seedlings in the cold test was recorded after the completion of this test in order to examine the effect of N and P nutrition on seed vigour as determined by seedling dry weight. From the analysis of variance presented in

Total nutrient levels (mg per plant)	Weight (g)	Total nutrient levels (mg per plant)	Weight (g)
N_1 = 100	0.726	P_1 = 25	0.488
N_2 = 1000	0.700	P_2 = 250	0.833
		P_3 = 500	0.850
		P_4 = 1000	0.683

Significance levels:

N:	N.S.	P: 1.0%	N x P: N.S.
5% LSD	N: 0.128	P: 0.181	N x P: 0.256

Table 87. The effect of N and P nutrition levels on the seedling dry weight on completion of the cold test in Experiment 2.

Table 87 it can be seen that the seedling dry weight was only affected significantly by P levels at the 0.1% significance level.

As shown in Figure 177, there is very little difference between seedling dry weights of different N levels, and that it was increased with increasing levels of P from P_1 to P_2 with no change from P_2 to P_3 and declined from P_3 to P_4 in this experiment and in the orders of $N_1 \simeq N_2$ and $P_3 \simeq P_2 > P_4 > P_1$.

Figure 178 shows the effect of NP interaction on the seedling dry weight on completion of the cold test.

4.4.7.3 Experiment 3: Cold test: Seedling Dry weight

The seedling dry weight of the total seedlings in the cold test was recorded at the end of the test in order to examine the effect of N, P and K nutrition on seed vigour as determined by the seedling dry weight. From the analysis of variance presented in Table 88 it can be seen that levels of P and K and their interactions NP, NK, PK and N x P x K significantly affected the seedling dry

Total nutrient levels (kg per ha)	Weight (g)	Total nutrient levels (kg per ha)	Weight (g)	Total nutrient levels (kg per ha)	Weight (g)
N_1 = 0	3.062	P_1 = 0	2.899	K_1 = 0	3.116
N_2 = 25	3.434	P_2 = 50	3.219	K_2 = 25	3.680
N_3 = 75	3.195	P_3 = 150	3.573	K_3 = 75	3.496

Significance levels:

N: N.S. N x P: 1.0%

P: 1.0% N x K: 5.0% N x P x K: 5.0%

K: 5.0% P x K: 5.0%

L.S.D. 5%
(N,P,K) = 0.398 (NxP,PxK,NxK) = 0.689 (N x P x K) = 1.194

Table 88. The effect of N, P and K mineral nutrition levels on on seedling dry weight on completion of the cold test in Experiment 3.

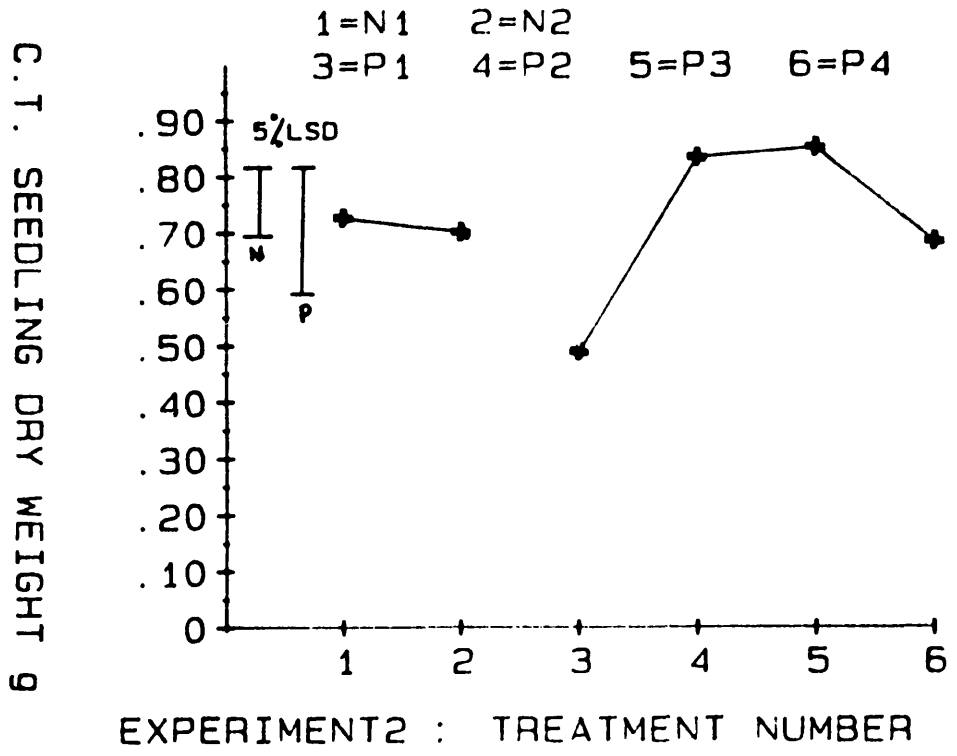

Figure 177. The main effect of N and P mineral nutrition levels on seed vigour as determined by the seedling dry weight on completion of the cold test.

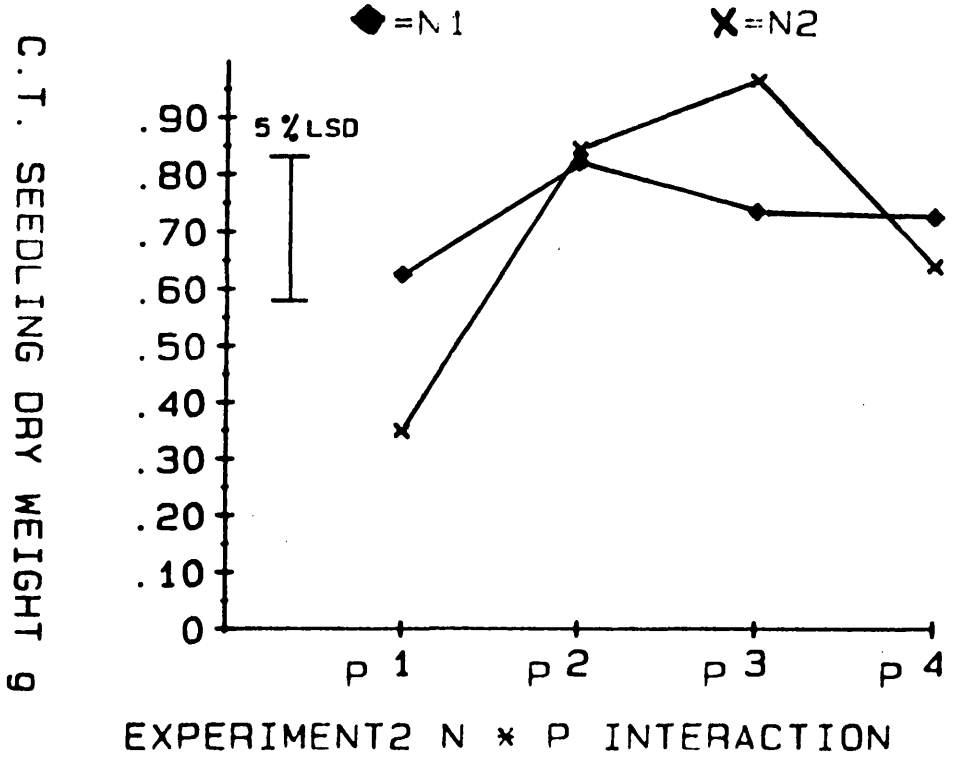

Figure 178. The effect of NP interaction on seedling dry weight on completion of the cold test.

weight at the 1.0%, 5.0%, 1.0%, 5.0%, 5.0% and 5.0% levels respectively.

As can be seen from Figure 180, the seedling dry weight increased with increasing P levels in the order of $P_1 < P_2 < P_3$ and that the K levels also increased but in the order $K_2 < K_1 < K_3$.

Figures 179, 181, and 182 show the effect of NP, NK and PK interactions on the seedling dry weight respectively. The highest seedling dry weight in the NP interaction was achieved by N_3P_3 (3.916 g) and the lowest by N_1P_1 (2.381 g). In the NK interaction the highest was achieved by N_2K_1 (3.711 g) and the lowest by N_1K_1 (2.552 g). And in the PK interaction the highest was achieved by P_3K_3 (4.183 g) and the lowest by P_1K_2 (2.680 g).

In the three way interaction (NPK), the highest seedling dry weight was achieved by the combination of $N_3P_3K_3$ (4.727 g) and the lowest by $N_1P_3K_1$ (1.923 g) in this experiment.

4.4.7.4 Experiment 4: Cold test: Seedling dry weight

The seedling dry weight of the total seedlings in the cold test was recorded after the completion of this test in order to examine the effect of N and K nutrition on seed vigour as determined by the seedling dry weight. From the analysis of variance presented in Table 89, it can be seen that only the levels of K nutrition significantly affected the seedling dry weight during this test at the 1.0% level.

As shown in Figure 183, the seedling dry weight increased with increasing levels of K in the order of $K_1 < K_2 < K_3 < K_4$ in this experiment.

Total nutrient levels (mg per plant)	Weight (g)	Total nutrient levels (mg per plant)	Weight (g)
N_1 = 0	6.23	K_1 = 0	4.76
N_2 = 100	5.80	K_2 = 50	5.62
N_3 = 500	5.05	K_3 = 250	5.83
N_4 = 1000	5.85	K_4 = 500	6.73

Significance levels:

N: N.S. K: 1.0%, and their interaction Nx K: N.S.

5% LSD = 0.91

Table 89. The effect of N and K nutrition levels on seedling dry weight on completion of the cold test in Experiment 4.

Figure 184 shows the effect of N and K interaction on seedling dry weight on completion of the cold test.

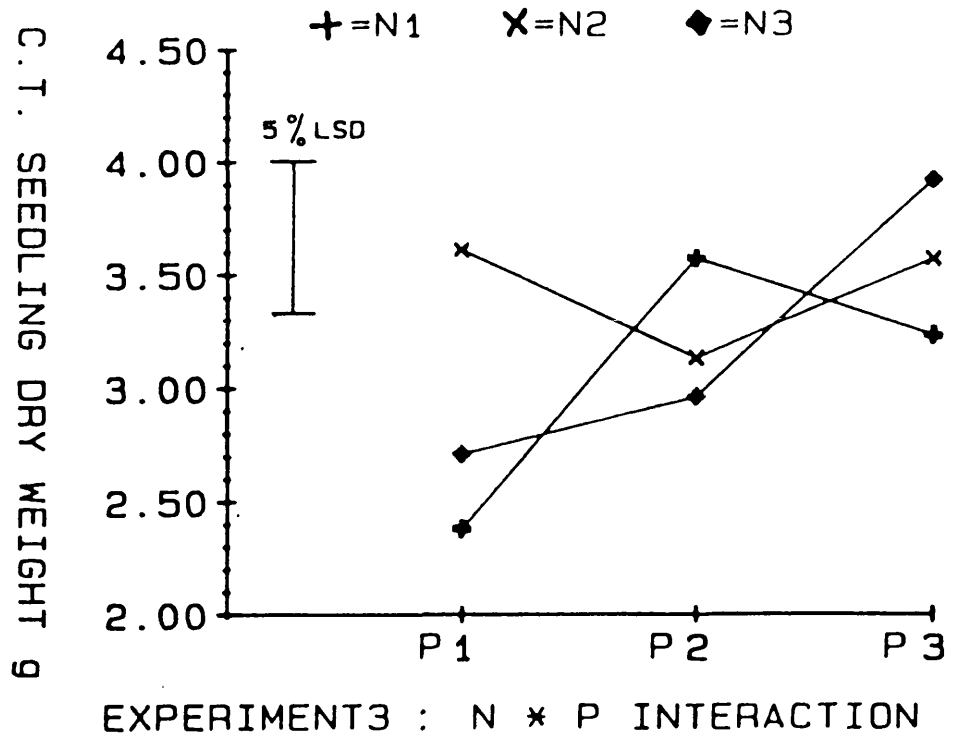

Figure 179. The effect of N x P interaction on seedling dry weight on completion of the cold test.

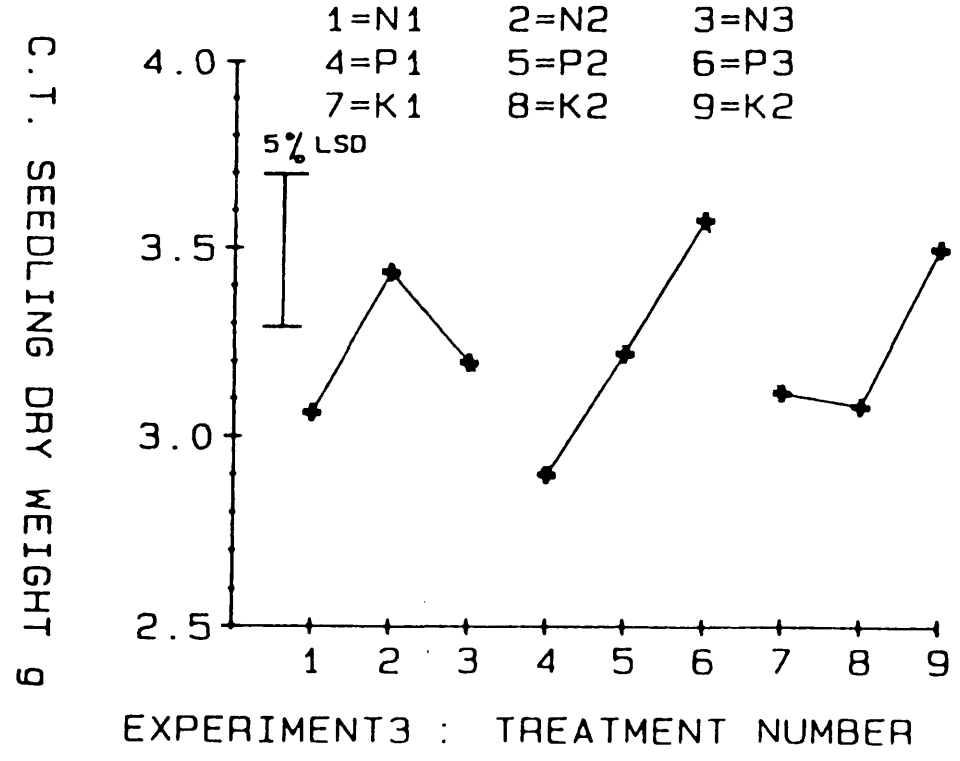

Figure 180. The main effect of N, P and K mineral nutrition levels on seed vigour as determined by the seedling dry weight on completion of the cold test.

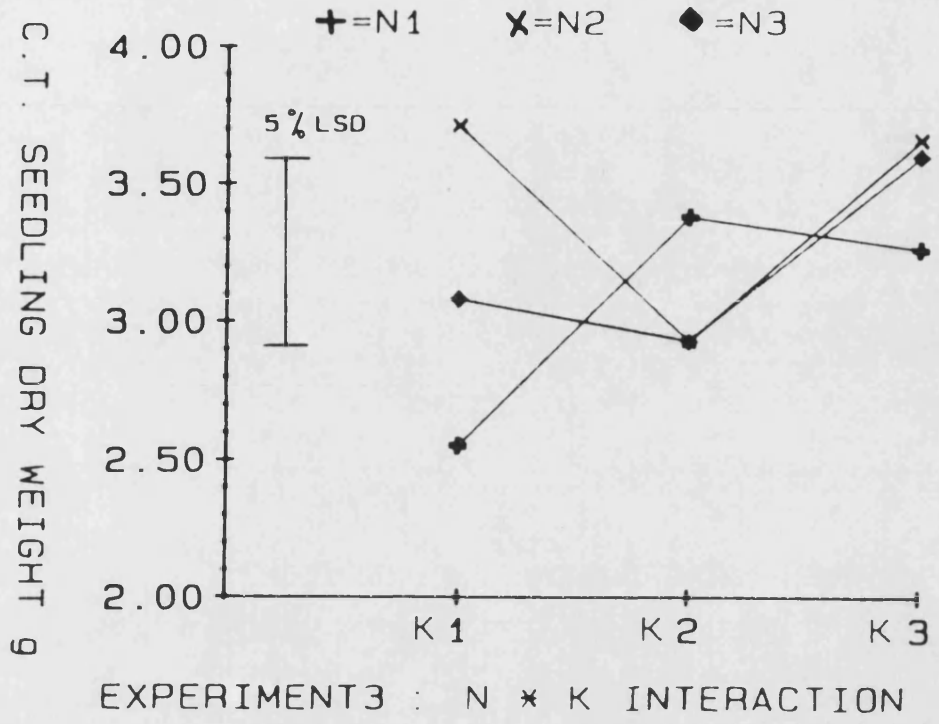

Figure 181. The effect of N x K interaction on seedling dry weight on completion of the cold test.

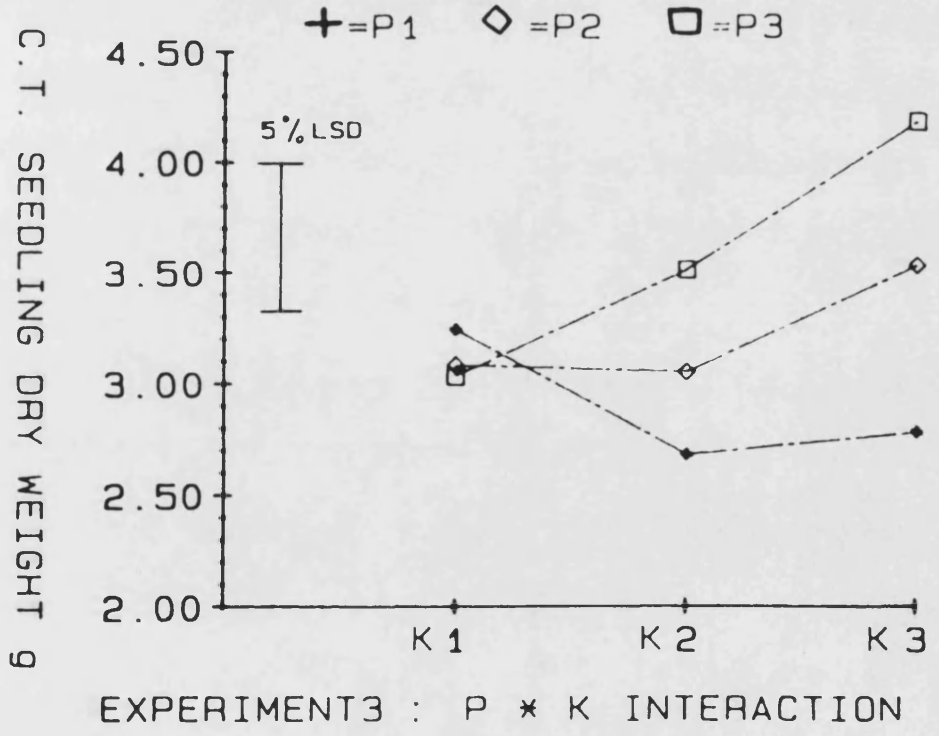

Figure 182. The effect of P x K interaction on seedling dry weight on completion of the cold test.

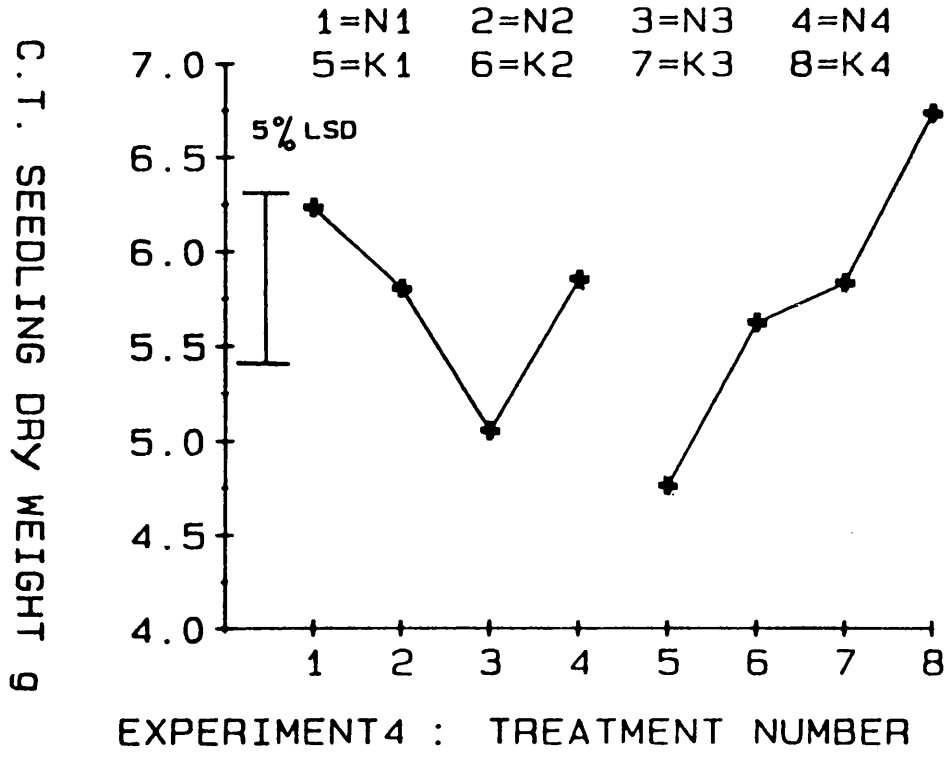

Figure 183. The main effect of N and K mineral nutrition levels on seed vigour as determined by the dry weight of the seedlings on completion of the cold test.

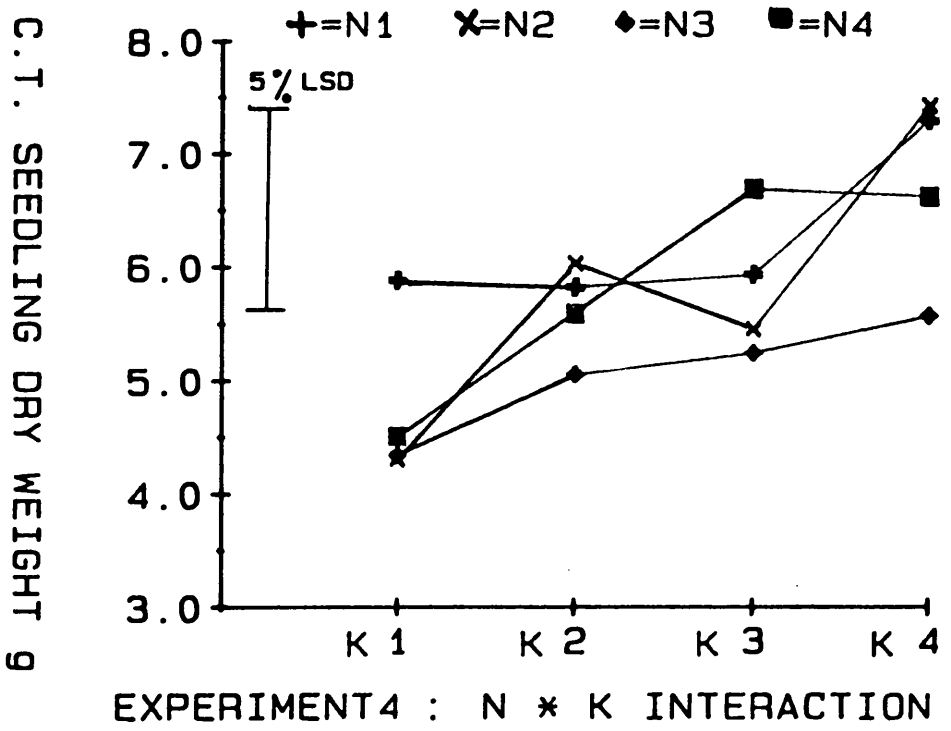

Figure 184. The effect of N x K interaction on the seedling dry weight on completion of the cold test.

4.4.8.1 Experiment 2: Total seed ATP content (Pm per g of air dried seeds)

In this experiment it was decided to measure the levels of ATP in pm per g of air dried seeds after 24 hours imbibition in order to examine the effect of N and P nutrition on seed yield as determined by the ATP levels. From the analysis of variance presented

Total nutrient levels (mg per plant)	Seed ATP content (pm per g)	Total nutrient levels (mg per plant)	Seed ATP content (pm per g)
N_1 = 100	64.0	P_1 = 25	71.3
N_2 = 1000	41.3	P_2 = 250	44.5
		P_3 = 500	40.5
		P_4 = 1000	54.2

Significance levels:

N:	5.0%	P: N.S.	N x P: N.S.
5% LSD	N: 18.36	P: 25.96	N x P: 36.71

Table 90. The effect of N and P nutrition levels on the total seed ATP content in Experiment 2.

in Table 90 it can be seen that only the levels of N significantly affected the total seed ATP content at the 5.0% significance level.

As shown in Figure 185 the level of N decreased seed ATP content as they increased whereas levels of P had similar effect but not significantly in this experiment, in the orders of $N_2 > N_1$ and $N_1 > N_4 > N_2 > N_3$.

Figure 186 shows the effect of NP interaction on total ATP content of seeds.

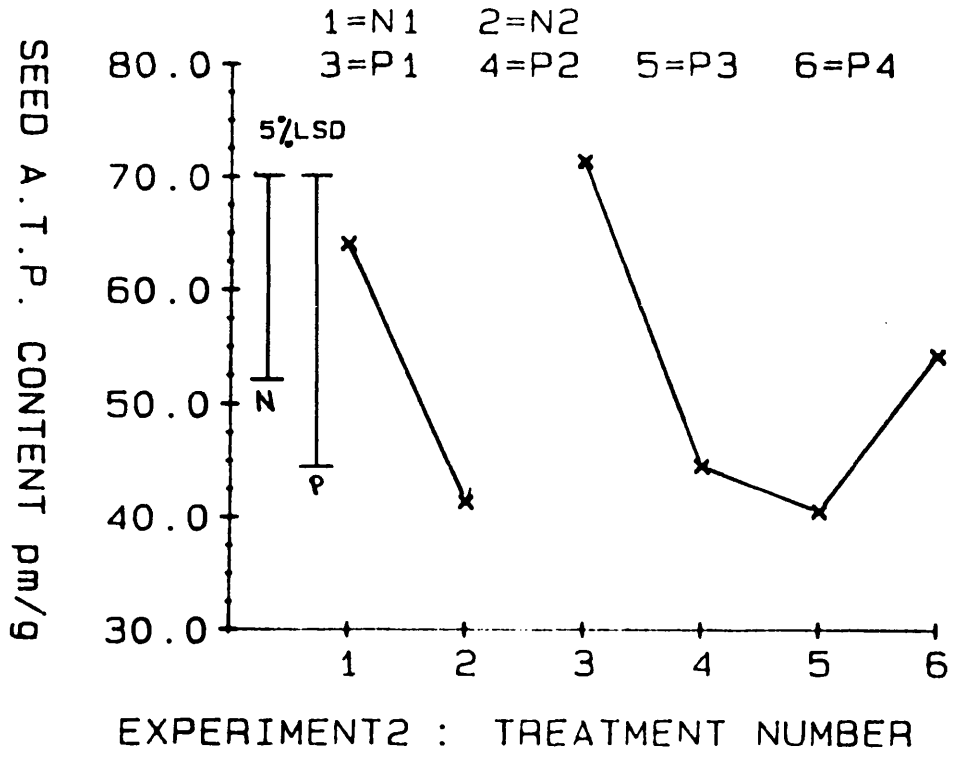

Figure 185. The main effect of N and P mineral nutrition levels on seeds' total ATP content after 24 hours imbibition in pm per g of air dried seeds.

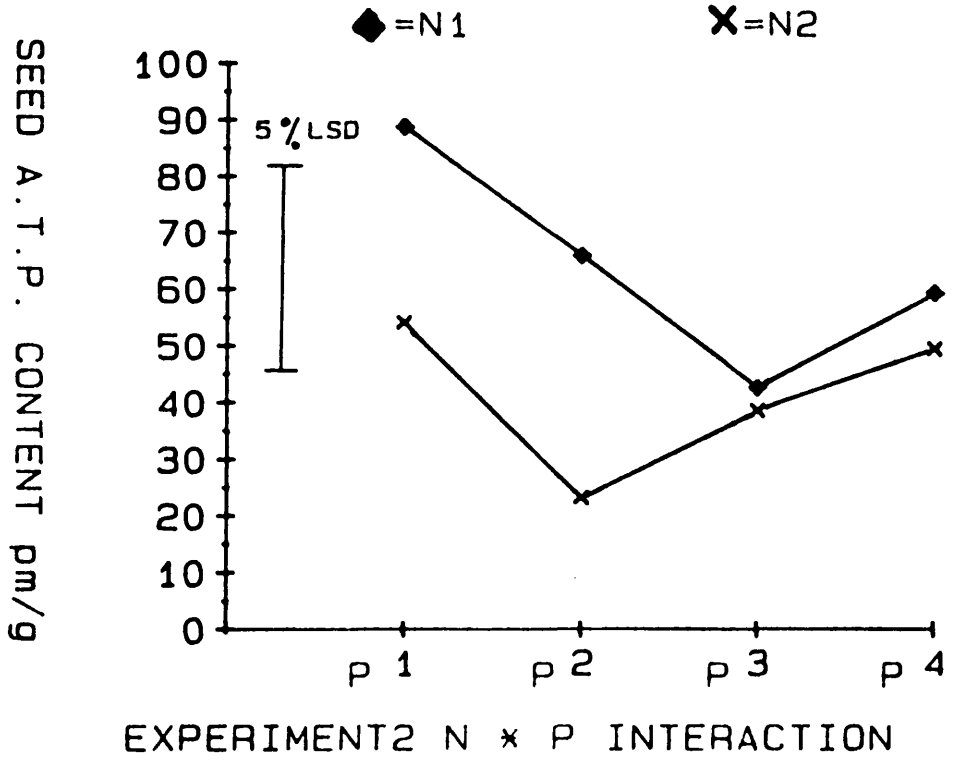

Figure 186. The effect of NP interaction on seed ATP content.

5. DISCUSSION

5.1 Plant Growth

The effect of mother plant nutrition on plant growth was studied in all experiments. The examination of the effect was in terms of plant dry weight, measured after harvest when all the pods and seeds had been removed. The plants were then cut just above the soil surface and were dried at 102°C for 8 hours.

Experiment	1	2	3	4
Plant average dry weight (g per plant)	2.36	1.99	4.66	3.45

Table 91. The average plant dry weight per plant achieved in Experiments 1, 2, 3 and 4.

As can be seen Experiment 3 resulted in the highest plant dry weight followed by Experiment 4 and the figures from Experiments 1 and 2 which are almost half that of 3 are similar. This inter-experimental variation of levels follows the same pattern of volume of substrate per plant in each experiment as shown in Table 92.

Experiment	1	2	3	4
Litres of compost per plant	2	1.5	3.62	2

Table 92. Volume of substrate per plant in Experiments 1, 2, 3 and 4.

Experiments 1, 2 and 4 were all container grown with each plant being allocated 2 L of growth media, whereas Experiment 3 was a field

crop with a plant density of 50 per m^2 and assuming that only the top 20 cm of the soil was mainly used by the plants, this means each plant had been allocated 4 L of soil as opposed to 2 L of compost in the other three experiments. The results from Experiments 1, 2 and 4 are also a reflection of the size of the containers. In Experiment 1, 10 L pots, in Experiment 2, 14 L pots and in Experiment 4, 40 L pots were used. The size of the pots has had very little effect in the first two experiments, whereas the mean plant dry weight increased considerably in Experiment 4.

Tables 11, 12, 13 and 14 show the main effect of N, P and K mineral nutrition levels on the vegetative plant as measured by plant dry weight in Experiments 1, 2, 3 and 4. In all the glasshouse experiments (1, 2 and 4) the levels of N significantly affected the plant dry weight. As can be seen from Figures 11, 13 and 17, increasing levels of N have increased plant dry matter by 15% in Experiment 1, 36% in Experiment 2 and 50.8% in Experiment 4. The levels of N have not significantly affected the plant dry matter in Experiment 3 which was grown in the field, and the plant dry weight was only increased by 8.8% with increasing levels of N. There are two possible explanations as to why such a response difference should exist between glasshouse and field experiments. Firstly, due to the relatively sterile conditions of peat (the main ingredient of the growth media used in the glasshouse experiments), the compost would contain very little or no nitrogen fixing bacteria, *Rhizobium leguminosorum* and thus the plants relied and responded to the mineral nitrogen supply in Experiments 1, 2 and 4. This explanation is further supported by the absence of root nodules on plant roots when examined at the conclusion of the glasshouse experiment. Nodules were observed

on roots of plants from the field experiment. The second explanation is the fact that during the summer of 1985, high rainfall as shown in the rainfall chart (Figure 7) could have possibly leached out most of the nitrogen and for this matter possibly even the other two nutrient inputs P and K to some extent.

However, the results from Experiment 3, despite its small and non significant effect, are still interesting as shown in Figure 15. After the initial soil analysis, the recommendation for nitrogen was 25 kg per ha for an early pea crop, which in this experiment is represented by N_2 and has considerably increased the plant dry weight compared to N_1 (N_1 = 0 kg per ha), whereas the third level of N (75 kg per ha) has had a negative effect from N_2 to N_3, highlighting the lack of response to over fertilization.

Phosphorus nutrition, a variable ingredient in Experiments 1, 2 and 3 have only significantly affected the plant dry weight in the glasshouse experiments, 1 and 2, as presented in Tables 11 and 12. Figures 11, 13, and 15 show the main effect of phosphorus levels on plant dry weight, as a measure of plant growth, in Experiments 1, 2 and 3. In Experiment 1, the phosphorus nutrition levels range from 50 mg per plant in P_1 to 210 mg per plant in P_4 and the plant dry weight has significantly increased with increasing P levels. Whereas in Experiment 2, the range of phosphorus nutrition is from 25 mg per plant in P_1 to 1000 mg per plant in P_4 and only a significant positive increase is achieved from P_1 to P_2 (P_2 = 250 mg per plant) and further increases in P have no, and eventually a negative effect on plant dry weight. It seems that the optimum P level with respect to plant dry weight production is 250 mg per plant under these experimental conditions. The increase in plant dry weight due to the main effect of

phosphorus has been a 20.6% increase in Experiment 1, 32.5% in Experiment 2 and 10.9% in Experiment 3.

Potassium mineral nutrition, a variable ingredient in Experiments 1, 3 and 4 have had no significant effect on plant growth as measured by plant dry weight in any of the experiments. However, the effect of potassium follows the same trend in all these experiments, as shown in Figures 11, 15 and 17. An increase in plant dry matter is only achieved from K_1 to K_2 in all three experiments (i.e. in Experiment 1, K_1 = 40mg per plant, K_2 = 60 mg per plant, in Experiment 3, K_1 = 40 kg per ha. and K_2 = kg per ha and in Experiment 4, K_1 = 0 mg per plant and K_2 = 50 mg per plant) and any further increase from K_2 to K_3 (i.e. in Experiment 1, K_3 = 120 mg per plant in Experiment 3, K_3 = 75 kg per ha, and in Experiment 4, K_3 = 250 mg per plant) has a negative effect on plant dry weight. The plant dry weight increase due to the main effect of potassium is 3.9% in Experiment 1, 7.8% in Experiment 3 and 14.4% in Experiment 4.

From the analysis of the nutrient interactions it is only the NP interaction in Experiment 2 (Table 12) that has had any significant effect on plant dry matter. As can be seen from Figure 14, at low levels of N (i.e. N_1 = 100 mg per plant) plant dry matter is increased but not significantly with increasing levels of P, whereas at the higher level of N (i.e N_2 = 1000 mg per plant), the response is complicated and even reduced by increasing levels of P. The restriction in growth could be due to the nitrogen supply becoming the limiting factor if the growth is to continue at the same rate. In general the response of the vegetative growth to N and P was more marked than the response to K. These observations are in agreement with our knowledge of the role of N, P and K in plant growth and

development. It is well known that nitrogen is of extreme importance to plants because it is a constituent of proteins, nucleic acids and many other important substances. Phosphorus is also extremely important as a structural part of many compounds, notably nucleic acids, and phospholipids. In addition, phosphorus plays an indispensible role in energy metabolism. Potassium appears to have no structural role in plants, but it serves a number of catalytic roles and is very important in the overall metabolism of plants. Many enzymes, for example, several involved in protein synthesis, do not act efficiently in the absence of potassium (Bidwell, 1979).

A satisfactory vegetative growth, in these experiments, measured in terms of the plant dry matter, is important in the ability of the pea plant to produce seeds. In all experiments this was supported by a high and significant correlation coefficient existed between plant dry matter and seed yield factors such as seed number, and seed dry weight as shown in Table 93.

	Plant dry weight			
Experiment	1	2	3	4
Seed number per plant	.831***	.445 N.S.	.677**	.800**
Seed dry weight	.784***	.670*	.403 NS	.553 NS

Table 93 Coefficient correlations between plant dry weight and seed yield.

Critical values of Correlation Coefficient for specified levels of significance in a two-tailed test:

Experiment		5% = *	1% = **	0.1% = ***
1	n = 12	.5324	.6614	.7800
2 and 4	n = 8	.6319	.7646	.8721
3	n = 9	.6021	.7348	.8471

5.2 Seed Yield

Yield is a useful parameter for determining whether the nutrient supply is adequate and balanced, as any severe deficiencies would ultimately reduce yield. Austin (1966b) examined the effect of nitrogen and phosphorus nutrition on pea seed production from plants grown in normal strength Hewitts solution and solutions containing one tenth of the normal concentration of nitrogen, one tenth of that of phosphorus and one tenth that of nitrogen and phosphorus. He found that increasing the nitrogen concentration produced an 80% increase in seed yield per plant, increasing phosphorus concentration produced a 70% seed yield increase, and increasing both elements together resulted in a 400% increase in yield. In a study made by Browning (1980) on the effects of nitrogen and phosphorus on seed yield and seed nutrient content in *Pisum sativum* L cv. Sprite, she reported a seed yield increase of 55% due to the combined effect of high nitrogen and phosphorus in an experiment, which was spring-sown. In subsequent experiments during the summer, nitrogen had no effect on seed yield and a response to phosphorus was obtained in only one of two experiments.

All the parameters related to seed yield will be discussed here under this heading and include: a) number of pods per plant; b) pod dry weight per plant; c) number of seeds per plant; d) seed dry weight per plant and e) seed number per pod.

In the first experiment, the number of pods per plant was only significantly affected by the levels of phosphorus and potassium (Table 15) and there is no marked difference between number of pods per plant due to difference in nitrogen levels. The slight increase which was achieved by the plants receiving the third level of N

compared with those receiving the first level of N is 0.29 of a pod which is a 6.9% increase, and this trend is passed on to pod dry weight, and number of seeds per plant (Tables 16 and 17). In this experiment the number of pods per plant, number of seeds per plant, and seed dry weight per plant increased (FIgures 19, 23 and 25) with increasing levels of phosphorus (Table 15, 17 and 18). Plants receiving the fourth level of phosphorus produced 20.5% more pods, 23.1% more seeds and 18.4% more seed yield per plant over those receiving the first level of phosphorus. Although the highest of the above parameters was achieved by the fourth level of P, the effects of the third level of phosphorus is very similar to that of the fourth level, suggesting that P_3 (140 mg per plant) is near the optimum under the experimental conditions and the further increase to P_4 (210 mg per plant) increased the yield insignificantly.

Nitrogen and phosphorus levels have had very little effect on pod dry weight and the number of seeds produced per pod (Tables 16 and 19).

In the same experiment, the number of pods per plant, pod dry weight per plant, seed number and seed dry weight per plant were decreased by increasing levels of potassium and only significantly in the case of pod number per plant (Tables 15, 16, 17 and 18). Whereas the number of seeds per pod was increased highly significantly with increasing levels of potassium (Table 19 and Figure 27). The increase in the number of seeds per pod has cancelled the negative effect of potassium on pod number and seed number per plant, so that the seed yield i.e. seed dry weight, is not significantly affected and is relatively comparable with the yields from nitrogen and phosphorus

treatments, but slightly lower. Potassium levels have had no significant effect on pod dry weight.

In the case of number of seeds per plant and number of seeds per pod, an interaction between P and K levels is present (Tables 17 and 19 and Figures 24 and 28). From the interaction between P and K and their effect on the number of seeds per plant, the effect of phosphorus can be confirmed and it can be concluded that the highest levels of phosphorus and potassium combination (P_4K_4) produced 44.4% more seeds than the combination P_1K_3. Similarly, from the effect of PK interaction on the number of seeds per pod it can be concluded that the combination P_2K_3 produced 21.2% more seeds per pod that the combination P_4K_1.

In the case of number of seeds per pod, an interaction between N, P and K is present (Table 19). From this interaction the interactive effect of the three elements are demonstrate and it can be concluded that the combination $N_3P_2K_3$ produced 60.7% more seeds per pod than the combination $N_2P_4K_3$.

In the second experiment the number of pods per plant increased with increasing levels of N (Table 20) significantly. Thus the plants receiving the second level of N produced 51.0% more pods per plant than the first level of N (Figure 29). The effect of nitrogen continued to be present in the pod dry weight per plant, number of seeds per plant, seed dry weight per plant and had no effect on the number of seeds per pod (Tables 21, 22, 23 and 24). The second level of nitrogen increased the pod dry weight by 65.3% (Figure 31), seed number by 55.90%, (Figure 33) and seed dry weight by 84.7% (Figure 35). Since the number of seeds per pod was the same for all the nitrogen levels it seems that the increase in the number of pods per

plant is responsible for the increase in the seed yield per plant.

In this experiment only seed dry weight per plant and seed number per pod were just significantly affected by the levels of phosphorus (Tables 23 and 24). However, the number of pods per plant, pod dry weight per plant, seed number per plant and seed dry weight per plant follow the same trend (Figures 29, 31, 33, 34 and 35), in that there is an increase from the first level of phosphorus to the third level of phosphorus and then they begin to decrease with the further increase in phosphorus level from P_3 to P_4. Plants receiving the third level of phosphorus produced 46.5% more pods per plant, 14.7% more pod dry weight, 37.8% more seed number and yielded 66.4% more seed in terms of dry weight, than the plants receiving the first level of phosphorus.

The interaction between nitrogen and phosphorus levels have significantly affected pod number per plant, pod dry weight per plant, seed number per plant, seed dry weight per plant and seed number per pod (Tables 20, 21, 22, 23 and 24). Examining these interactions in Figures 30, 32, 34 and 36, it can be observed that they all have the same pattern confirming the effect of nitrogen and phosphorus in this experiment. The combination N_2P_4 produced 185.8% more pods per plant than N_1P_4, and that the combination N_2P_4 produced 374.1% more pod dry weight than N_1P_4, also the combination N_2P_4 produced 322.9% more seeds per plant than N_1P_4 and that N_2P_4 produced 374.1% more dried seeds than N_1P_4, also that the combination N_2P_4 gave 49.4% more seeds per pod than the combination N_1P_4.

In the third experiment, in which samples were grown in the field, the seed yield parameters are only seed number per plant and seed dry weight per plant. The reason for the absence of pod count and pod

related measurements is that a high rate of pod and haulm separation followed by immediate pod drying was necessary, following harvest, because of the relatively very high moisture content of some of the pods and seeds on the plants. It was then decided not to slow down the operation by collecting these data, in order to minimize the risk of post harvest seed deterioration caused by fungal activities.

In this experiment, seed number per plant and seed dry weight per plant were not affected significantly by any of the N, P and K levels, nor by any of their interactions (Tables 25 and 26). However, nitrogen levels have slightly increased seed number (Figure 39) by 11.21% from the first level of N to the second level of N and by 10.40% from the first to the third level of N, and with very little change from the second to the third level of N. Similarly, nitrogen levels have increased seed dry weight (Figure 41), by 13.56% from the first to the third nitrogen level and by 10.72% from the first to the second nitrogen level with very little change from the second to the third nitrogen level. Phosphorus and potassium levels have had insignificant effect on the number of seeds and seed dry weight per plant in this experiment (Tables 25 and 26). The lack of response of seed yield to the nutrient inputs in this experiment are due to the same factors which were explained earlier, that affected plant dry weight, mainly the high rainfall during the production period, especially during late June (Figure 7) when for example, 42 mm of rain fell on June 21st, the nutrients could either have been washed off or leached out at a very early stage of plant growth.

In the fourth experiment, pod number per lant, pod dry weight per plant, seed number per plant, seed dry weight per plant and the number of seeds per pod are highly significantly affected by the four levels

of nitrogen supply (Tables 27, 28, 29, 30 and 31). The pattern of response is the same in all of these parameters (Figure 43, 45, 47, 49 and 51), in that increasing levels of N have increased seed yield in general after an initial slight decrease from first level of N to the 2nd level of N. Thus the plants receiving the second level of nitrogen produced the least number of pods per plant, the lowest pod dry weight per plant, the lowest seed number per plant and the lowest seed dry weight per lant. The number of pods per plant increased by 47.74% from N_2 to N_4 and by 34.38% from N_2 to N_3 and by 9.67% from N_3 to N_4, and by 35.71% from N_1 to N_4. Pod dry weight also increased by 35.8% from N_2 to N_4, by 22.26% from N_2 to N_3, and by 10.76% from N_3 to N_4. Seed number per plant has also increased by 32.60% from N_1 to N_4, by 20.86% from N_2 to N_4 and by 9.71% from N_3 to N_4. Seed dry weight per plant has increased by 33.84% from N_2 to N_4, by 22.2% from N_2 to N_3 and by 9.46% from N_3 to N_4. Although the number of seeds per pod is significantly affected by the levels of nitrogen (Table 31), and decreased with increasing levels of nitrogen, the resulting differences are less than one seed and are thus not of practical importance. So, assuming that the number of seeds produced per pod is the same for all, the increase in seed dry weight is due to the increase in pod number in this experiment.

On the other hand, the potassium levels in this experiment have only significantly affected the seed number per plant, seed dry weight per plant and seed number per pod (Tables 29, 30 and 31). The pattern of response is similar to that of nitrogen levels except that there is a slight increase from the first level up to the third level in all the seed yield parameters with the fourth level either having a negative effect in the case of pod number per plant, and seed number

per plant, or no effect in the case of pod dry weight per plant, seed dry weight per plant and seed number per pod (Figures 43, 45, 47, 49 and 51). The increase in pod number per plant from K_1 to K_3 is 4.3% and the decrease due to K_4 from K_1 is 2.83%. Pod dry weight per plant only increased by 11.40% from plants receiving the third level of potassium over plants receiving the first level. Seed number per plant was increased by 32.0% in plants receiving the third level of potassium over those receiving the first level, and it declined by 2.53% in plants receiving the fourth level of potassium over those receiving the third level. Seed dry weight per plant was increased by 67.66% in plants receiving the fourth level of potassium over those receiving the first level, and by 66.85% in plants recieving the third level of potassium over those receiving the first, indicating that the increase from the third to the fourth level of potassium has had very little effect on seed dry weight.

Seed number per pod also increased by the increasing level of potassium. It has increased by 28.8% in plants receiving the fourth level of potassium over those receiving the first, and by 23.90% in plants receiving the third level of potassium over the first, also indicating that the increase from the third to fourth level of potassium had very little effect on seed number per pod. Thus, as the increase in pod number per plant is very small, by increasing the potassium supply, the increase in seed number per pod is mainly responsible for the increases in seed number per plant and seed dry weight per plant.

Apart from the N and K main effects on seed yield, in the fourth experiment, an interaction between N and K was found (Tables 29 and 30) that has significantly affected seed number per plant and seed

dry weight produced by a plant. From these interactions presented in Figures 48 and 50, it can be seen that the highest level of N in combination with the third level of K produced the greatest number of seeds, and the highest seed dry weight per plant. The seed number per plant was increased by 106.6% by plants receiving the treatment combination of N_4K_3 than those receiving the treatment N_1K_1. The seed dry weight per plant was also increased by 155.7% by plants receiving the treatment combination of N_4K_3 over those receiving the combination N_1K_1. In this experiment, in general, the greatest seed yield per plant was from the combination of the highest level of nitrogen and potassium.

The overall picture of the four experiments with regard to their effect on seed yield is that increasing nitrogen levels increased seed yield in all the experiments, phosphorus in the first and second and not the third experiment, whereas the effect of potassium was on the pod set i.e. number of seeds per pod rather than the seed yield, i.e. seed number or seed dry weight. The most dramatic effects were demonstrated by the nutrient combinations i.e. their interactions, highlighting the dependency of one for optimum performance on the others.

The seed yield parameters were found to be highly significantly correlated in all the experiments as shown in Table 94.

From the summary in Table 95, and the previous discussion, regarding the effect of mother plant nutrition on seed yield parameters, the following conclusions can be drawn.

a) The increasing levels of nitrogen nutrition have increased plant dry weight, number of pods, pod dry weight, seed number and seed

dry weight per plant and has either not affected or decreased the number of seeds per pod in these experiments.

b) Increasing levels of phosphorus nutrition have also increased plant dry weight, number of pods, pod dry weight, number of seeds and seed dry weight per plant and have either not affected or decreased the number of seeds per pod in these experiments.

c) Increasing levels of potassium nutrition have increased the number of seeds per pod, had either no effect or increased pod dry weight, seed number and seed dry weight per plant, also had either no effect or decreased number of pods per plant and had no effect at all on plant dry weight.

	Experiment	Plant dry weight per plant	Pod number per plant	Pod dry weight per plant	Seed number per plant	Seed dry weight per plant
Pod number per plant	1	.725** †				
	2	.607 NS				
	3	-				
	4	.944 ***				
Pod dry weight per plant	1	.753 **	.740 **			
	2	.649 *	.929 ***			
	3	-	-			
	4	.937 ***	.933 ***			
Seed number per plant	1	.831 ***	.889 ***	.711 **		
	2	.445 NS	.965 ***	.445 NS		
	3	.677 *	-	-		
	4	.800 **	.762 *	.924 ***		
Seed dry weight per plant	1	.784 ***	.772 **	.732 **	.868 ***	
	2	.670 *	.988 ***	.953 ***	.958 ***	
	3	.403 NS	-	-	.908 ***	
	4	.553 NS	.523 NS	.769 **	.928 ***	

Table 94. The correlation coefficients between the seed yield paramaters /contd.....

	Experiment	Plant dry weight per plant	Pod number per plant	Pod dry weight per plant	Seed number per plant	Seed dry weight per plant
Seed number	1	.237 NS	-.239 NS	-.068 NS	.228 NS	.235 NS
per pod	2	- .314 NS	.319 NS	.420 NS	.537 NS	.334 NS
	3	-	-	-	-	-
	4	-.227 NS	-.381 NS	-0.48 NS	.301 NS	.560 NS

Table 94 (continued) The correlation coefficients between the seed yield parameters.

† Critical values of the correlation coefficient for specified levels of significance in a two-tailed test

Experiment		5% or *	1% or **	0.1% or ***
1	n = 12	.5324	.6614	.7800
2 and 4	n = 8	.6319	.7646	.8721
3	n = 9	.6021	.7348	.8471

	Experiment	Plant dry weight per plant	Number of pods per plant	Pod dry weight per plant	Number of seeds per plant	Seed dry weight per plant	Number of seeds per pod
Levels of	1	↑	N/E	↑	N/E	↑	N/E
nitrogen	2	↑	↑	↑	↑	↑	N/E
fertilizers	3	↑	-	-	N/E	↑	-
	4	↑	↑	↑	↑	↑	↓
Levels of	1	↑	↑	↑	↑	↑	N/E
phosphorus	2	↑→↓	↑→↓	N/E	↑	↑	↓
fertilizers	3	N/E	-	-	N/E	N/E	-
	4	-	-	-	-	-	-
Levels of	1	N/E	↓	N/E	N/E	N/E	↑
potassium	2	-	-	-	-	-	-
fertilizers	3	N/E	-	-	N/E	N/E	-
	4	N/E	N/E	↑	↑	↑	↑

Table 95. Summary of the effects of the levels of N, P and K supply in seeds from Experiments 1, 2, 3 and 4 on plant dry weight, pod number, pod dry weight, seed number and seed dry weight per plant and seed number per pod.

↑ = increase, ↓ = decrease, N/E = not affected - not includes as a variable in the experiment.

5.3 Seed Chemical Composition

Chemical elements can play three distinct roles in plants; electrochemical, structural and catalytic. Electrochemical roles include balancing of ionic concentrations, stabilization of macromolecules and colloids and charge neutralization. Structural roles are played by elements that are incorporated into the chemical structure of biological molecules or used in forming structural polymers (e.g. calcium in pectin, phosphorus in phospholipids). Catalytic roles are played by elements involved in the active site of enzymes (Bidwell, 1979).

The chemical elements which are concerned in crop nutrition are normally classed in two groups known as macro (or major) and micro (or trace) elements. The list of macronutrients include carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium and sulphur. The plants obtain the first three from the photosynthesis of carbon dioxide and water. The micronutrient elements which are required by plants in only very small amounts are boron, chloride, copper, iron, manganese, molybdenum and zinc (Bunt, 1976; Flegmann and George, 1975).

As seed is the starting point in most plants' growth and development cycle, it is therefore important that it has sufficient reserves for a healthy and strong start during seed germination and seedling establishment prior to the establishment of an efficient root function.

In this study the effect of mother plant mineral nutrition on seed chemical composition was determined by measuring the total amount of the following elements: nitrogen, phosphorus, potassium, magnesium, manganese, iron and copper, in the seeds harvested from plants grown

Browning (1980) in her work on pea nutrition of the same cultivar reported a percentage protein content ranging from 24.6 to 38.8% in the glasshouse experiments.

In the glasshouse experiments, 1, 2 and 4, significant increases in the seed nitrogeni content were obtained by increasing the plant nitrogen supply (Tables 33, 34 and 36), whereas the increase in the nitrogen supply had no significant effect on the seed nitrogen content in the field experiments (Table 35). The increase was 19.31% from the first level of N to the fourth in Experiment 1, and 66.8% in Experiment 2 and 22.56% in Experiment 4 from the second level of nitrogen to the fourth (Figures 54, 57 and 61).

The increase in seed nitrogen or protein content due to nitrogenous fertilizer has also been found by Ries (1971) with beans; Schweizer and Ries (1969); Lowe, Ayers and Ries (1972) with wheat and oat; Lopez and Grabe (1973) with wheat; Browning (1980) with peas, Gavras (1981) with beans *(Phaseolus vulgaris* L.) and Liaw (1982) with beans *(Phaseolus vulgaris* L.).

In Experiments 1 and 4 an increasae in potassium supply has significantly reduced the seed total nitrogen content (Tables 33 and 36) and in Experiment 2, where the potassium supply was the same for all the treatments, an increase in the nitrogen supply has reduced the seed total potassium content (Table 42 and Figure 77), with a similar effect in Experiment 4 (Table 44 and Figure 81).

The increase in nitrogen supply decreased seed phosphorus content in Experiments 3 and 4 (Tables 39, 40, Figures 69, 71) and increased in Experiment 2 (Table 38, Figure 67). Bates (1971) claims that there is an antagonistic effect of uptake of one nutrient on the concentration of the plant of another nutrient which can often be

detected by plant and seed analysis.

Increasing the levels of both phosphorus and potassium nutrition supply have tended to reduce seed nitrogen content in Experiments 1, 2 and 4 (Figures 54, 57 and 61) and had no significant effect in Experiment 3 (Table 35).

Seed phosphorus content

Phosphorus is present in relatively large quantities in the protoplasm and nucleus of cells. It is a component of nucleic acids and sugars and is essential for many of the energy tranfer processes, such as photosynthesis and the breakdown of carbohydrates, which occur in plant (Bunt, 1976).

The phosphorus containing constituents of seed can be described in terms of four groups of compounds; phytic acids, nucleic acid, lipid and protein (Dalling and Bhalla, 1984). Most of the phosphorus present in seeds is in the form of phytin. Guardiola and Sutcliffe (1978) found the level to be 53% of total phosphorus in peas. An important role of phytase activity in phytin degradation is in the formation of the nucleic acids, DNA and RNA of various types, essentialy in the early growth during seed germination and seedling development. Phytin reserves are mainly located inside protein bodies and are especially concentrated in the globoid crystals, where deposited as a salt compex compound with a variety of cations (e.g. K, Mg, Mn, Fe, Cu, Zn) needed for the early growth prior to root absorption.

The membranes of probably all cells and subcellular organelles contain phospholipids in organised association with the membrane proteins. The phospholipids play an important role in the membrane

transport of divalent ions especially calcium, and in the membrane structure (Anon, 1983).

Austin and Longden (1966) and Austin (1966a) studied vigour of peas, carrots and watercress plants obtained from seeds which were produced by plants grown in nutrient solutions each with a different concentration of phosphorus. When the seedlings were grown on nutrient containing a high phosphorus content, they showed no evidence of the mother plant's nutrition. However, when the seedlings were grown on low concentrations of phosphorus, the size of the seedlings was directly related to the concentration of phosphorus in the nutrient medium of the mother plant; this phosphorus concentration was also reflected in the phosphorus content of the seed.

Browning (1980) working with peas reported a 0.39 to 0.95% increase in total seed phosphorus content based on seed dry weight when phosphorus supply was increased in her glasshouse experiments, whereas phosphorus supply had no effect on seed phosphorus content in her field experiment.

From the results obtained in these experiments addition of phosphorus fertilizer has increased total seed phosphorus content in the glasshouse experiments, Experiments 1 and 2 significantly (Tables 37 and 38), whereas under field conditions it had no effect (Table 39), confirming Browning's (1980) results. The increase in seed phosphorus content was 87.8% from the first level of phosphorus to the fourth in Experiment 1 and in Experiment 2 the increase was 234.2% for the same level of phosphorus nutrition (Figures 63, 67). In both experiments the increase in seed phosphorus content is markedly reduced at higher levels of phosphorus nutrition, for example, in Experiment 1, the increase was 13.27% from the third to the fourth

level of phosphorus, and in Experiment 2 the increase was 1.2% for the same level of phosphorus nutrition.

Different levels of nitrogen fertilizers have had no effect on seed total phosphorus content except in Experiment 2 (Table 38), when it was increased by 19.76% from the first level of nitrogen to the second level of nitrogen supply (Figure 67).

Potassium nutrition of the mother plant has also had no significant effect on seed total phosphorus content except in Experiment 1 (Table 37) when it decreased by 10.48% by an increase of potassium supply from the second level to the fourth (Figure 63).

The effect of phosphorus nutrition in seed nitrogen content agrees with the work with peas reported by Randall, Thompson and Schreoder (1979), in that the seed nitrogen content decreases as plant phosphorus supply increases above the deficiency level. This trend was observed in Experiment 1 (Figure 54), Experiment 2 (Figure 57) and Experiment 3 (Figure 59).

Seed potassium content

Potassium is a major cell base and is most important in balancing the negative charge of organic acids produced within the cell and of anions such as sulphate, chloride and nitrate absorbed by the roots from the external medium. A second important function of potassium is that of an activator for several enzymes in plant meatbolism and biosynthesis (Bunt, 1976).

Potassium in seed is stored as a phytic and salt complex, which upon metabolism during the early growth of the seedling provides the functional and structural constituents required (particularly ATP, coenzymes and nucleic acids) prior to an efficient root absorption (Ching, 1972).

In these experiments nitrogen and phosphorus supply have produced a greater effect on seed total potassium content than potassium supply. Only in Experiment 4 (Table 44) did the potassium content of the seed increase by increasing levels of potassium supply (Figure 81), by as much as 50.87% from the first level of potassium to the fourth, and in the same experiment, the increase in nitrogen supply decreased the potassium content of the seed by as much as 19.8% from the first level of nitrogen to the fourth (Figure 81). In Experiment 2, where potassium nutrition was supplied equally to all the plants in the different treatments, total seed potassium content was decreased by increasing nitrogen supply (Table 42), whereas the increase in the phosphorus nutrition supply increased seed potassium content (Figure 77) in the same experiment. The different nutrient levels supplied in the outdoor experiment (Experiment 3) have had no consistent and significant effect on seed total potassium content (Table 43).

Potassium fertilizer application reduced the seed nitrogen content, thus protein, in Experiments 1 and 4 (Figures 54, 61). Sheveleva (1973) working with peas and beans *(Phaseolus vulgaris* L.) reported a similar trend, where the seed protein content of peas was reduced in some cases by potassium fertilizers and bean seed protein content increased by 1.1% after an application of 60 kg K_2O per hectare. Potasium fertilizer had no consistent effect on seed phosphorus content, although the tendency in Experiments 1, 3 and 4 (Figures 65, 69 and 71) is towards a slight reduction of phosphorus with increasing levels of potassium.

Seed magnesium content

The most important known role of magnesium is as a constituent of chlorophylls a and b, which each contain about 2.7% Mg and together represent about 10% of total leaf magensium. Magnesium is also important in the stability of ribosomal particles, especially polysomes in the protein synthesis from amino acids. Many enzymes are also activated by magnesium (Anon, 1983). Magnesium in seeds is also stored as a phytic acid salt complex, which upon metabolism during the early growth of the germinating seed provides the required magnesium, prior to an efficient good root absorption (. CHing, 1972).

In these experiments in which all treatments received the same level of Mg, seeds' total magnesium content was significantly affected by the nitrogen nutrition supply in the glasshouse Experiments 1, 2 and 4 (Tables 45, 46, 48) and only by the phosphorus supply in Experiment 2 (Table 46). Seeds' total magnesium content increased with increasing levels of nitrogen supply in Experiments 1, 2 and 4 (Figures 83, 85 and 89), however, in Experiment 1, it initially decreased, but not significantly and in Experiment 4, the seeds' magnesium content decreased with the final increase in nitrogen supply. Increasing the levels of phosphorus nutrition also increased seed magnesium content by as much as 30.1% in Experiment 2 from an increase from the first level of phosphorus supply to the fourth (Figure 85). Increasing the levels of potassium nutrition supply has had no significant effect on seed magnesium content, in any of the experiments.

Seed manganese, iron and copper content

Manganese is a constituent of enzyme systems concerned with respiration, nitrogen metabolism and the transference of phosphate.

Whilst it is not a constituent of chlorophyll, it is found in high concentrations in the chlorophyll containing tissue and a deficiency of manganese prevents chlorophyll formation (Bunt, 1976). In peas, manganese deficiency is also responsible for the 'marsh spot' disorder and must be guarded against or very heavy losses may be incurred since affected peas are unsaleable, for human consumption or as seed (PGRO, 1984).

The extreme importance of Iron in plant material is related to two important facts, iron is part of the catalytic site of many important oxidation-reduction enzymes, and is essential for the formation of chlorophyll, though it is not part of the molecule. In addition, iron may be structurally involved in lamellar lipids in the nucleus, chloroplast, and mitochondria and appears to be required for the synthesis of membrane protein (Bidwell, 1974).

Copper on the other hand, plays exclusively catalytic roles in plants, being part of a number of important enzymes such as polyphenol oxidase and ascorbic acid oxidase. It is also present in chloroplasts in plastocyanin, an important member of photosynthetic electron transport system, and it may also be involved in nitrate reduction.

Minerals are mainly stored in seeds as phytin salt complex compounds inside protein bodies, especially in the globoid crystals (Lott, 1984). Mineral cations may also be bound directly to reserve proteins, for example, a manganese-containing protein has been isolated from the protein bodies of the peanut (Rozacky, 1968). Lectins are also metalloproteins, and may contain manganese (Mn) and Calcium (Ca).

In these experiments, total seed's manganese content was affected by nitrogen, phosphorus and potassium nutrition supply in the glasshouse

experiments 1, 2 and 4 (Tables 49, 50 and 52) and the levels of these nutrients had no significant effect in the outdoor experiment (Table 51). In Experiments 1 and 4 (Figures 92 and 97) increase in the nitrogen nutrition supply increased seed manganese content, whereas in Experiment 2, it decreased the seed manganese content (Figure 93). The levels of phosphorus nutrition in Experiment 1 have also decreased seed manganese content (Figure 92) and have increased in Experiment 2 (Figure 93). The levels of potassium nutrition supply have dereased seed manganese content significantly in both Experiments 1 and 4 (Figures 92 and 97).

The levels of nitrogen, phosphorus and potassium nutrition have only significantly affected the total seed iron content in Experiment 1 (Table 53) and only nitrogen levels in Experiment 2 (Table 54). In Experiment 1, the seed total iron content decreased with increasing levels of N, P and K (Figure 99), whereas the seed iron content increased with increasing levels of nitrogen in Experiment 2 (Figure 101). Increasing levels of potassium nutrition supply decreased the seed iron content in Experiment 4 (Figure 105) as well as in Experiment 1 (Figure 99), whereas in Experiment 3 (Figure 103), the seed iron content increased with increasing levels of potassium supply

Nitrogen, phosphorus and potassium nutrition have significantly affected the totalseed's copper content in Experiment 1 (Table 57) and that only nitrogen levels in Experiments 3 and 4 (Tables 59 and 60). Increasing the levels of nitrogen supply reduced the seed copper content in Experiments 1, 2, 3 and 4 (Figures 107, 109, 111, 113) by as much as 45% in Experiment 4 from the first level to the fourth nitrogen levels supplied. Increasing the levels of phosphorus nutrition decreased seed copper content in Experiment 1 (Figure 107),

after an initial rise, but produce inconsistent effects in the other experiments. Increasing the levels of potassium nutrition increased the seed total copper content in Experiments 1, 3 and 4 (Figures 107, 111, 113). In Experiment 4, the increase in seed copper content was as for the third level of potassium and then decreased at the fourth level.

From the summary of the results in Table 98, and the discussion presented above, the following overall conclusions on seed chemical composition in all the experiments can be drawn.

a) Increasing the levels of nitrogen supply increased seed nitrogen, magensium and manganese contents, decreased seed phosphorus, iron and copper content, but had no consistent effect on seed potassium content.

b) Increasing the levels of phosphorus supply increased seed phosphorus, potassium, magnesium, manganese and copper content, decreased seed nitrogen content and had no consistent effect on seed iron content.

c) Increasing the levels of potassium supply increased seed potassium and seed copper content, decreased seed nitrogen, phosphorus, magnesium, manganese and iron content.

	Experiment	N content	P content	K content	Mg content	Mn content	Fe content
N content	1						
	2						
	3						
	4						
P content	1	-.302 NS					
	2	.160 NS					
	3	.544 NS					
	4	-.419 NS					
K content	1	.062 NS	.556 *				
	2	-.603	.198 NS				
	3	.170 NS	-.118 NS				
	4	-.756 *	.355 NS				
Mg Content	1	.399 NS	-.309 NS	.225 **			
	2	.652 *	.650 *	-.236 NS			
	3	.012 NS	-.036 NS	.208 NS			
	4	-.228 NS	-.113 NS	-.427 NS			
Mn Content	1	.861 ***	-.443 NS	.142 NS	.680 ***		
	2	-.921 ***	-.103 NS	.768 **	-.453 NS		
	3	-.264 NS	-.092 NS	.261 NS	-.244 NS		
	4	.765 **	-.436 NS	-.952 ***	.371 NS		

Table 97 The correlation coefficients between the seeds' chemical composition in Experiments 1,2,3 and 4. /contd....

	Experiment	N content	P content	K content	Mg content	Mn content	Fe content
Fe content	1	-.021 NS	-.523 **	-.461 NS	.004 NS	.238 NS	
	2	.837 **	.110 NS	.631 *	.460 NS	-.805 ***	
	3	-.229 NS	-.324 NS	.022 NS	.712 *	.212 NS	
	4	.310 NS	-.046 NS	-.726 *	.735 *	.737 *	
Cu content	1	-.468 NS	-.289 NS	-.329 NS	.258 NS	.331 NS	-.205 NS
	2	-.607 NS	.614 NS	.699 *	.060 NS	.673 *	-.529 NS
	3	.281 NS	.838 **	-.495 NS	.084 **	-.056 NS	.057 NS
	4	-.505 NS	.732 *	.521 NS	-.200 NS	-.728 *	-.441 NS

Table 97 continued

Critical values of the correlation coefficient for specified levels of significance in a two-tailed test.

Experiment		5% *	1% **	0.1% ***
1	n = 12	.5324	.6614	.7800
2 and 4	n = 8	.6319	.7646	.8721
3	n = 9	.6021	.7348	.8471

	Experiment	N content	P content	K content	Mg content	Mn content	Fe content	Cu content
Levels of nitrogen nutrition	1	↑	N/E	↑	↑	↑	↓	↓
	2	↑	↑	↓	↑	↓	↓	↓
	3	N/E	↓	↑	N/E	N/E	N/E	↓
	4	↑	↓	↓	↑	↑	↑	↓
Levels of phosphorus nutrition	1	↓	↑	↑	N/E	↓	↓	↓
	2	↓	↑	↑	↑	↑	N/E	↑
	3	↓	↓	N/E	N/E	↑	↑	↑
	4	-	-	-	-	-	-	-
Levels of potassium nutrition	1	↓	↓	N/E	N/E	↓	↓	↓
	2	-	-	-	-	-	-	-
	3	N/E	↓	N/E	N/E	N/E	↑	↑
	4	↓	N/E	↑	↓	↓	↓	↑

Table 98. Summary of the effects of the levels of N, P and K supply in seeds from Experiments 1, 2, 3 and 4 on seeds' total N, P, K, Mg, Mn, Fe and Cu content.

↑ = increase, ↓ = decrease, N/E not affected - not included as a variable in the experiment

5.4 Seed quality

The germination percentage and seedling growth vary with the quality of seed. Factors affecting seed quality can be listed as follows:

1) Genetical quality (i.e. purity of species and purity of cultivar within the same lot).
2) Physiological quality (i.e. viability and vigour).
3) Health condition (i.e. freedom from pests and diseases).
4) Purity (i.e. presence or absence of weed seeds and other undesirable material).
5) Morphological quality (including size, stage of development and incidence of damage). and
6) Moisture content (the seed must be dried sufficiently in order to minimize deterioration).

In these experiments the effect of N, P and K mineral nutrition levels of the mother plant on seed quality was determined by the following methods:

1) Seed size, which was determined by individual seed weights in all experiments and 1000 seed weight in Experiment 3.
2) Germination percentage under ideal conditions, as specified by the ISTA rules.
3) Seedling evaluation at the end of the germination test.
4) Seedling dry weight.
5) Seed leachate conductivity measurement.
6) Percentage germination under the cold test as specified by the ISTA rules, and
7) Seed ATP measured in the seeds after 24 hours of imbibition (Experiment 2 only).

The first two are normal seed quality tests and the remaining 5 are means of determining vigour levels in seeds.

5.4.1 Seed size

Seeds are easily separated by diameter, weight or density. For distinction in vigour it is the weight and the density, rather than the volume of the seed that are important, and the thousand seed weight of seed lots is in fact given as part of the sales information (Heydecker, 1974).

Pollock and Roos (1972) stated that for a given species and cultivar, the larger or heavier the seed, the greater will be the percentage germination and the more vigorous will be the growing seedlings. Heydecker (1974) also observed that the larger seeds often, with more initial capital do have at least an initial advantage over the smaller ones. The interest in the effect of seed size on seed germination and seedling establishment has continued up to date, from when F. Noble in his 'Handbuch der Samenkunde' (Perry, 1976) the original textbook of seed testing published in 1876, noted that the larger seeds of cereals produced larger seedlings than small seeds from the same ear of the mother plant.

The variation in seed size within a genotype may have several causes, for example, nutrition of mother plant, po sition on the inflorescence and stage of maturity at harvest. The effect of mother plant nutrition on seed size has been reported by several workers.

The beneficial effect of nitrogen nutrition on seed size of peas was observed by Browning (1980) in beans *(Phaseolus vulgaris* L.) by Ries (1971), Gavras (1981), and Liaw (1982). A similar effect was found by Singh and Cheema (1972) with radish, by Lopes and Grabe

(1973) on wheat seed, by Austin and Longden (1966) on carrots, by Soffer and Smith (1974b) with lettuce and Rault (1983) with cauliflower.

Browning (1980) working with peas reported that high seed phosphorus concentration was associated with small seed size, which were produced by plants receiving the high phosphorus treatments. Austin (1966b) also found that phosphorus produced changes in seed size as well as seed composition in peas, with high phosphorus seed being 15% larger than low phosphorus seed and he concludes that the improved performance of high phosphorus seeds was due to the concentration effect and not to the effect of total amount of reserves.

Iwata and Eguchi (1958), working with Chinese cabbage found plants which were supplied with phosphorus during the early stages only produced a lower seed yield due to small size of seeds compared with that of control plants which were supplied with phosphorus during all growth stages. Gavras (1984) working with beans, reported that the bean plants receiving low levels of phosphorus produced lower seed yield but larger seeds, which agreed with results obtained by Maxon Smith (1976) working with lettuce.

The results from these experiments indicate that the seed size as determined by mean seed dry weight, was only significantly affected by nitrogen levels in Experiment 2 (Table 62), phosphorus levels in Experiment 1 (Table 61) and potassium levels in Experiment 4 (Table 65). The nutrient levels have had no effect on the mean seed weight or 1000 seed weight in the field experiment (Experiment 3; Table 63).

In Experiment 2, the increase in nitrogen supply has increased mean seed weight by 19.1 % (Figure 117) and the trend in Experiments 1

and 3 (Figures 115, 117) is towards an increase although not significantly.

Increasing phosphorus levels in Experiment 1 (Figure 115) has initially decreased mean seed weight, i.e. from first level of phosphorus to the second and further increases have tended to increase mean seed weight, but not significantly. In Experiment 2 (Figure 117), increasing levels of phosphorus nutrition from the second to the fourth levels has decreased mean seed weight by 17.4% and in the same experiment the mean seed weight increased by 21.4% by increasing the level of phosphorus supply from the first to the second level.

Increasing the levels of potassium nutrition has clearly increased the mean seed weight in Experiment 4 (Figure 123), by as much as 30.2% by an increase from the first level of potassium to the fourth level of potassium.

A summary of the overall effect of mother plant nutrition on seed size is presented in Table 109. Seed size was found to be significantly and positively correlated with the seedling dry weight at the end of the cold test, seedling dry weight at the end of the germination test and negatively correlated with the conductivity test. Seed size showed no consistent significant positive or negative correlation with seed nutrient content as shown in Table 99.

5.4.2 Germination test

High viability is to be expected in seeds which have been hand harvested, slowly dried and not subject to long periods of storage. Thus the germination percentage of all seed produced was fairly high, ranging from 78.7% to 100.0%, as shown in Table 100.

	Experiment	N	P	K	Mg	Mn	Fe	Cu	G.T. % germination	G.T. % normal seedlings	G.T. seedling dry weight	Conductivity test	C.T. % germination	C.T. seedling dry weight
Seed size as determined by seed mean weight	1	-.021	.587* †	.546*	-.110	- 0.233	-.838***	-.086	- 0.037	-.605*	.012	-.656*	.263	.793**
	2	.699*	.534	-.482	.457	-.835**	.617	-.233	.010	-.148	.662*	.170	.047	.652*
	3	-.369	-.627*	.825**	-.695	.302	-.173	-.515	.042	.717*	.677*	-.670*	-.287	-.047
	4	-.515	-.276	-.571*	-.386	-.655*	-.580	-.033	.619	.803**	.842**	-.382	.714*	.773**

Table 99. The correlation coefficients between seed size (seed mean weight) and seed nutrient content, seed quality and seed vigour tests.

† Critical values of the correlation coefficient for specified levels of significance in a two-tailed test.

Experiment		5% or *	1% or **	0.1% or ***
1	n = 12	.5324	.6614	.7800
2 and 4	n = 8	.6319	.7646	.8721
3	n = 9	.6021	.7348	.8471

Experiment	Maximum	Minimum	Average
1	100	90.5	98.19
2	100	78.7	94.83
3	95.3	79.3	85.93
4	100	92.7	97.17

Table 100. The range of the percentage of germination achieved in Experiments 1, 2, 3 and 4

The nitrogen application did not affect the germination percentage in Experiments 1, 3 and 4 (Tables 66, 68 and 69) significantly and only in Experiment 2 (Table 67), was the effect significant. In this experiment the higher levels of nitrogen supply resulted in lower germination percentage than the lowest level (Figure 129). The reduction is as much as 10.0% from the lowest to the highest level of nitrogen. This reduction effect can also be observed in Experiments 1 and 3 (Figures 125 and 132), but it was not significant. The seedling dry weight taken at the 9th day from sowing was affected significantly by the levels of nitrogen supply in Experiments 1 and 4 (Tables 70 and 73). In both of these experiments seedling dry weight sharply decreased as far as the third level of N and increased at the fourth level (Figures 135 and 142).

A possible explanation for this inverse response on the percentage germination and seedling dry weight by the levels of nitrogen nutrition is that, lower levels of nitrogen produced smaller seeds (Figures 115, 117 and 119), which imbibe water during early stages of germination faster than the larger seeds.

The levels of phosphorus supply significantly affected percentage germination and seedling dry weight in Experiments 1 and 2 (Tables 66 and 67, 70 and 71). In Experiment 1, although the effect of phosphorus supply on the percentage germination is significant, the difference between the lowest (P_4 = 97.8 %) and the highest (P_2 = 99.2 %;Figure 125) is 1.4 %, which is almost negligible, and even in the interactions between NP, NK and PK (Figures 126, 127 and 128), the lowest percentage germination is not less than 95.0%. In Experiment 2, however, increasing levels of phosphorus supply has increased the percentage germination (Figure 129), up to the third level of phosphorus and further increase (i.e. up to the fourth level) has had a negative effect. From the graph of N and P interaction (Figure 130), it can be seen that at the low level of nitrogen, increasing phosphorus levels have no effect and it is only at the higher level of nitrogen, that increasing phosphorus levels help improve the effect that the higher nitrogen level had on the percentage germination in this experiment. The interaction of the higher levels of N and P such as N_2P_3, have reduced percentage germination by 5% compared with the N_1P_3 interaction, but have compensated for this reduction by producing almost 40% heavier, therefore larger, seeds (Figure 130), 120% higher dry weight of seed per plant (Figure 35), and 66% higher number of seeds per plant (Figure 33),in this experiment. Increasing levels of phosphorus supply increased seedling dry weight in Experiment 1 (Figure 135) and Experiment 2 (Figure 138).

Increasing levels of potassium nutrition have had no significant effect on the percentage germination in any of the experiments and had only significantly affected the seedling dry weight in Experiment 4 (Table 78). In this experiment seedling dry weight increased with

increasing levels of potassium from the first to the third level by as much as 20%.

Most of the reported work on the effect of mother plant nutrition on seed quality has not found any effect on seed germination. For example. Austin and Longden (1965) did not find differences in germination of watercress, pea and carrot seed due to different mother plant nutirition. Singh and Cheema (1972) working with radish, also reported no significant effect on germination percentage due to different mother plant nutrient treatments. Maxon Smith (1976) did not find differences in lettuce seed germination due to different mother plant phosphorus treatment. Gavras (1980) working with beans reported no significant effect on germination percentage due to nitrogen application, and the higher levels of phosphorus had depressed the germination percentage and seedling dry weight. Osman (1982) reported that with sweet pepper the main effects of N, P and K and their interactions on germination percentage were not significant.

On the other hand, Fox and Albrecht (1957) working with wheat found that seedling emergence was improved when the nitrogen content of the seed had been increased by the fertilizer supplied to the mother plant. Soffer and Smith (1974b) found a positive linear correlation between nitrogen levels and seedling emergence. Liaw (1982) reported that with beans, increased nitrogen appplication to the mother plants produced seeds which were higher in percentage germination and germinated earlier, and that plants receiving higher levels of phosphorus produced seeds which were lower in percentage germination and slower to germinate.

A summary of the overall effect of mother plant nutrition on the percentage germination and seedling dry weight at the end of the

germination test is presented in Table 109. Percentage germination and seedling dry weight were found to be significantly and negatively correlated with the seed conductivity and seed nitrogen content but not significantly. The percentage germination in the cold test correlated positively and significantly with the percentage germination in the germination test. The correlation coefficients between percentage germination and seedling dry weight of the germination test and seed nutrient content and seed vigour tests are shown in Table 101.

5.4.3 Seedling evaluation

The resulting seedlings from the germination test were assessed on the ninth day from sowing prior to seedling dry weight measurement, into the following categories (according to the guidelines described by the Official Seed Testing Station (OSTST) Cambridge, UK (Anon, 1977): I) Normal seedings, II) abnormal seedlings, III) ungerminated seeds, IV) dry seeds and V) dead seeds. The effect of mother plant nutrition on the percentage of normal seedlings are only discussed here. This percentage was calculated by dividing the number of seedlings in the normal category by the total number of seeds that have germinated (i.e germination percentage) and then multiplying by one hundred.

In these experiments the levels of nitrogen nutrition have only significantly affected the percentage of normal seedlings in Experiment 2 (Table 75) and have had no significant effect in any of the other experiments. In Experiment 2, increasing levels of nitrogen supply has decreased the percentage of the normal seedlings (Figure 147) by as much as 18.3% from the highest to the lowest level of nitrogen. This reduction can also be seen in Experiment 4 (Figure 151).

The levels of phosphorus nutrition have had no significant effect on the percentage of normal seedlings in any of the experiments. However, the trend in Experiments 1 and 2 (Figures 144 and 147) has been towards a reduction effect on the percentage of normal seedlings by increasing the levels of phosphorus supply from lowest to highest.

The levels of potassium nutrition supply have significantly affected the percentage of normal seedlings in Experiments 1 and 4 (Tables 74 and 77). In Experiment 1, increasing levels of potassium decreased the percentage of the normal seedlings (Figure 144) from the second level to the fourth level by 13.6% after an initial increasse from the first to the second level. In Experiment 4, on the other hand, increasing levels of potassium nutrition increased the percentage of normal seedlings (Figure 151) by 9.2% and further increases from the third to the 4th level had a slight negative effect.

A summary of the overall effect of mother plant nutrition on the percentage of normal seedlings is presented in Table 109.

The percentage of normal seedlings at the end of the germination test is positively correlated with the percentage of germination of the cold test and the germination test and is negatively correlated with the seed conductivity test, whereas no consistent correlation exists between the percentage of normal seedlings and the seed nutrient content as shown in Table 102.

	Experiment	N content	P content	K content	Mg content	Mn content	Fe content	Cu content	G.T. % normal seedlings	Seed conductivity	C.T. % germination	C.T. Seedling dry weight
Germination Test Percentage Germination	1	-.425	-.276	-.571*†	-.030	-.357	-.002	.721***	-.143	.059	.083	-.348
	2	-.609	0.439	0.407	-.334	.455	-.403	.756*	.843**	-.886**	.874***	.735*
	3	.497	.648*	-.551	-.458	-.230	-.463	.577	.465	.424	.687*	-.493
	4	-.429	-.028	.496	-.001	-.480	-.171	.057	.685*	-.318	.062	.208
Germination Test Seedling dry weight	1	-.284	.474	.498	.403	.005	-.084	.113	.214	-.203	-.279	.355
	2	.227	.777**	.197	.281	-.253	.250	.439	.295	-.363	.503	.907***
	3	.250	-.009	-.314	-.812***	-.033	-.488	-0.075	.725*	-.109	.113	-.376
	4	-.210	-.303	.644*	-.566	-.599	-.708*	0.030	.897***	-.438	.630	.741*

Table 101. The correlation coefficients between percentage germination and seedling dry weight in the germination test and seed nutrient content and seed vigour tests.

†See footnote to Table 99.

Seedling evaluation as determined by the percentage of normal seedlings in the germination test.	Experiment	N content	P content	K content	Mg content	Mn content	Fe content	Cu content	G.T. % germination	G.T. seedling dry weight	Seed conductivity	C.T. % germination	C.T. Seedling dry weight
	1	.192	-.264	-.249	.138	.368	.397	-.016	-.143	.214	.508	.236	-.290
	2	-.735**	.006	.453	-.739*	.508	-.589	.485	.843**	.295	-.982***	.943***	.541
	3	-.128	-.174	.681*	.540	.199	.089	.147	.465	.724*	-.063	.369	-.059
	4	-.538	-.064	.825**	-.434	-.827**	-.812	.341	.685*	.897***	-.124	.485	.757*

Table 102. The correlation coefficients between percentage of normal seedlings at the end of germination test and seed nutrient content and vigour tests.

See footnote to Table 99.

5.5 Vigour tests

Peas often have to be sown in late February or early March in Northern temperate regions such as the UK during cold, wet conditions, when establishment of seedlings can take up to six weeks. Under these circumstances a germination test alone is not always a reliable guide to potential field establishment. It is the ability of seeds to germinate and emerge under these adverse conditions that has been termed "seed vigour". Therefore additional tests to the germination test are necessary to identify those samples that could fail to emerge in these circumstances (PGRO, 1984).

5.5.1 Electrical conductivity test

The standard germination test is designed to give information on the planting value of seed offered for sale. The relationship between this test and emergence in the field is generally not very good for early sowing of peas, as some seed lots with high laboratory germination have low field emergence (Bedford, 1974).

The existence of this problem in peas has long been recognised (Eastham, 1925; Wellington, 1962). Matthews and Bradnock (1967) developed a test in which the electrical conductivity of water in which seeds have been steeped is related to their emergence in the field. This test depends on the fact that as seeds are being soaked in water, carbohydrates and inorganic salts are released; the greater the amount of these substances (leachates) that is released the lower is the degree of vigour and subsequently the more likely is the seed to fail to emerge in adverse conditions, due to invastion by *Pythium* spp. which are responsible for pre-emergence damping off.

Matthews and Bradnock (1968) reported a negative correlation between the electro-conductivity of the water in which pea seeds are soaked and seedling emergence. The electrical conductivity method for assessing the vigour of pea seed has become firmly established in the UK, by the seed trade, the Official Seed Testing Stations and food processors (Bedford, 1974).

The test involves the measurement of electrolytes in the leachate after the seeds have been soaked in deionized water for 24 hours. The results are expressed in micro Siemen (µs) per gram of seed, and is translated into vigour grades by PGRO (1984) as follows:

Up to 24 µs - High vigour = Suitable for early sowing.

25 to 29 µs - Medium vigour = Some seedbed losses may occur in adverse conditions, but can be used for later drilling in more favourable conditions.

30 to 43 µs - Low vigour = Not suitable for early sowing and may fail in cold, wet conditions.

Above 43 µs - Very low vigour = Not suitable for sowing at all.

In these experiments the average seed leachate's conductivity ranged from 10.48 to 34.11 µs per gram of seed (Table 103).

Except in Experiment 2, the results recorded from the other experiments (Table 103) fall within the high vigour category. This is to be expected from hand harvested and gently dried seed lots. Seeds from Experiment 2, on the other hand, fall within low and very low vigour category, but at the same time, they have achieved an average of 94.8 % germination in the germination test and 88.2 % germination

Experiment	Maximum	Minimum	Average
1	19.55	4.70	10.48
2	56.94	20.91	34.11
3	29.22	15.01	20.86
4	25.88	13.74	20.05

Table 103. The range of seed conductivity (μs per gram) recorded in Experiments 1, 2, 3 and 4

in the cold test (Tables 104 and 105), whereas the seeds from Experiment 3 (the field experiment) gave relatively low conductivity values and the poorest percentage germination under the cold test conditions.

The high conductivity readings recorded for seeds in Experiment 2 could be firstly due to seed N, P and K content. As can be seen from Table 106, these seeds had the highest nitrogen and iron and relatively high phosphorus and potassium content per gram of oven dried seed than the seeds from the other experiments.

Experiment	Maximum	Minimum	Average
1	100	92.43	98.19
2	100	78.67	94.83
3	95	79.34	85.93
4	100	92.67	97.17

Table 104. The range of germination percentage recorded on the 8th day of the germination test for Experiments 1, 2, 3 and 4.

Experiment	Maximum	Minimum	Average
1	100	82	97.05
2	98	68	88.25
3	76	22	50.8
4	86	57	71.3

Table 105. The range of germination percentage recorded on the 21st day of the cold test for Experiments 1, 2, 3 and 4.

Another reason for the high conductivity of the seeds from Experiment 2 could be due to the glasshouse air temperatures during the maturation and senescing periods. Experiment 2 experienced the highest average of maximum air temperatures during the months of August and September prior to harvest (30 C) (see Figures 1,3,6and9) causing quicker seed drying on the plant, leading to a higher number

Experiment	N mg per g	P mg per g	K mg per g	Fe µg per g	Cu µg per g
1	47.77	16.84	22.14	80.41	0.847
2	50.50	7.56	16.77	131.7	5.19
3	19.28	5.05	8.71	84.7	9.70
4	20.82	5.32	8.88	125.8	4.69

Table 106. The average seed nutrient content recorded per gram of oven dried seeds from Experiments 1, 2, 3 and 4.

of cracks in the seed coat. Although seed coat cracks were not assessed in any of the experiments, other workers, including Perry (1973), Powell and Matthews (1979b) and Biddle (1980), have shown that cracks in the testa produce high levels of leaching in pea seed.

The effect of mother plant nutrition on the conductivity of seed leachates in peas has only been reported by Browning (1980). In her experiments she concluded that the higher the seed nitrogen content, the lower the seed conductivity, and thus, the lower seed protein concentration and the reduced amounts of protein per seed are associated with high levels of leaching. Liaw (1982) working with beans, reported that increasing levels of nitrogen fertilizer supply to the mother plant produced seeds of lower conductivity. Increasing phosphorus nutrition had the opposite effect.

In these experiments, the levels of nitrogen supply have significantly affected the seed conductivity in all the experiments (1 to 4) (Tables 78, 79. 80 and 81). Increasing levels of nitrogen nutrition increased seed conductivity in Experiment 2 (Figure 157), decreased in Experiments 3 and 4 (Figures 159, 161), and had an inconsistent effect in Experiment 1 (Figure 153). The increase in Experiment 2 was by as much as 79.3% from the lowest to the highest level of nitrogen supply and the decreases in Experiments 3 and 4 were by 23.6% and 53.5% respectively, from the lowest to the highest level of nitrogen supply.

The levels of phosphorus supply have also significantly affected the seed conductivity in Experiments 1 and 2 (Tables 78 and 79). Increasing levels of phosphorus nutrition supply have decreased the conductivity of seed leachates in both of these experiments (Figures 153 and 157). The reduction in Experiment 1 (Figure 153) is as much as

88.4% by increasing the phosphorus supply from the lowest to the highest level, and in Experiment 2 (Figure 157) the reduction is 28.2%, when the phosphorus supply is increased from the first to the second level and any further increases in the phosphorus supply (i.e. from the second to third and to the fourth) increases the seeds' leachate conductivity, but not significantly. As can be seen from the graphs of the nitrogen and phosphorus interactions in these two experiments (Figures 154 and 158), the reduction effect of phosphorus levels is much more effective and pronounced at the highest levels of nitrogen supply.

The levels of potassium nutrition have also significantly affected the seed leachate's conductivity in Experiment 1 only (Table 78). Increasing levels of potassium nutrition supply decreased the seed leachate conductivity by 28.1% (Figure 153), by an increase from the first to the third level of potassium supply.

A summary of the overall effect of mother plant nutrition on the vigour test as determined by the seed leachate conductivity is presented in Table 109.

This test correlated negatively with the other seed quality and seed vigour tests such as seed size, percentage germination of the germination test and the cold test, as shown in Table 107. However, the correlation between seed nutrient content and seed leachates' conductivity was inconsistent in the four experiments.

5.5.2 Cold test

The cold test was originally developed for maize (*Zea mays* L.) by Isely (1957) for use when the results of germination tests carried out under the optimal conditions of temperature and moisture did not

	Experiment	N content	P content	K content	Mg content	Mn content	Fe content	Cu content	Mean seed weight	G.T. % germination	G.T. % normal seedling	G.T. Seedling dry weight	C.T. % germination	C.T. Seedling dry weight
Seed leachate conductivity	1	.311	-.812***	-.480	.386	.576*	.747**	.024	-.656*	.059	.508	-.203	.040	-.696
	2	-.713*†	-.042	-.476	.698*	-.522	.537	-.547	.170	-.886**	-.982***	-.363	-.957***	-.552
	3	.508	.843**	-.052	.207	.001	.134	.859***	-.670*	.424	-.063	-.109	.774**	.144
	4	-.254	.858**	.192	-.121	-.379	-.140	.875**	-.382	-.318	-.124	-.438	-.409	-.000

Table 107. Correlation coefficient between seed leachate's conductivity and seed nutrient content, seed quality tests and other seed vigour tests.

† See footnote to Table 99.

provide a reliable prediction of field emergence (Fiala, 1981). Since then the cold test has been developed as a reliable vigour test for many crops including peas. In this test, seeds are subjected to more realistic field germination and emergence conditions in the laboratory, by simulating the cold, wet and pathogenic conditions of an early spring soil. Seeds are sown in unsterilized soil, placed in cold conditions and later are transferred to high temperature favourable for germination. The results show the combined effect of low temperature and pathogens and no distinction is possible between them. The results are usually expressed as percentage germination but the growth rate of the plants may also be affected (Fiala, 1981).

A relationship between pea seed performance under the cold test conditions and the seeds' mother plant nutrition has not previously been reported. In these experiments the percentage germination and the total seedling dry weight at the end of the cold test (i.e. on the 21st day from sowing) were recorded.

Nitrogen levels have significantly affected the percentage germination in Experiments 1, 2 and 3 (Tables 82, 83 and 84) and the seedling dry weight in Experiment 1 (Table 86) only. Increasing levels of nitrogen supply increased the percentage germination in Experiment 1 (Figure 163) by 2.3% and in Experiment 2, it decreased (Figure 167) by 14.7% and in Experiment 3, it also decreasaed (Figure 169) by as much as 30.1%. The seedling dry weight was increased in Experiment 1 (Figure 173) by increasing the levels of nitrogen supply by 10.2 % from the lowest to the highest level.

Phosphorus levels have had no significant effect on the percentage germination in the cold test in any of the experiments, but the seedling dry weight was significantly affected by the phosphorus

levels in Experiments 1, 2 and 3 (Tales 86, 87 and 88). Increasing levels of phosphorus nutrition supply has increased seedling dry weight in Experiment 1 (Figure 173) by 19.6%, in Experiment 2 (Figure 177) by 80.8%, an increase of phosphorus supply from the first to the third level and a further increase to the fourth level had a negative effect. In Experiment 3, the seedling dry weight was increased (Figure 180), by 23.2% by increasing phosphorus supply from the lowest to the highest level.

Potassium levels have also significantly affected the percentage germination of seeds under the cold test conditions in Experiments 1 and 3 (Tables 82 and 83), and the seedling dry weight in Experiments 3 and 4 (Tables 88 and 89). Increasing the levels of potassium nutrition supply have increased the percentage germination in Experiment 1 (Figure 163) by 2.3% and in Experiment 3 (Figure 169) by 16.3%, when the potassium supply was increased from the second to the third level. Increasing levels of potassium has also increased the seedling dry weight in Experiment 3 (Figure 179) by 13.5 % and in Experiment 4 (Figure 183) by 41.4%.

A summary of the overall effect of mother plant nutrition on seed quality and vigour tests is presented in Table 109.

The correlation coefficients between the seed vigour test as determined by the percentage germination and seedling dry weight in the cold test with seed nutrient content and seed quality are presented in Table 108.

5.5.3 Adenosine triphosphate content and seed vigour

Ching (1982) stated that the energy status of seeds during formation, storage and germination is important in the expression of

	Experiment	N content	P content	K content	Mg content	Mn content	Fe content	Cu content	Mean seed weight	G.T. % germination	G.T. % normal seedlings	G.T. seedling dry wt.	Seed leachate conductivity	Cold Test % germination
Cold test % germination	1	.419	-.268	.097	.267	.337	-.516	.284	.263	.083	.236	-.279	.040	-
	2	-.560	.129	.370	-.635	.338	-.313	.473	.047	.874***	.943***	.503	-.957***	-
	3	.281	.763**	-.539	-.052	.159	.091	.930***	-.287	.687*	-.369	.113	.774**	-
	4	.021	-.434	.471	-.567	-.308	-.548	-.205	.714*	.062	.485	.630	-.409	-
Cold test seedling dry weight	1	.136	.850***	.620*	-.029	-.072	-.731**	.340	.793**	-.348	-.290	.355	-.696*	.081
	2	-.002	.713*	.135	.047	-.164	.080	.443	.652*	.735*	.541	.907***	-.552	.694*
	3	-.170	-.161	.466	.286	.829**	.627*	-.078	-.047	-.493	-.059	-.376	.144	.061
	4	-.270	-.013	.799**	-.763*	-.722	-.866**	.286	.773**	.208	.757*	.741*	-.000	.838**

Table 108. Correlation coefficient between percentage germination and seedling dry weight of the cold test and seed nutrient content, and other seed quality tests. † See footnote to Table 99.

seed vigour in terms of the rate of germination and rate of seedling growth. In general, the higher the energy status, the more and faster the growth. However, the metabolism of embryonic tissue is very dramatic and an oscillation of energy status prevails in the early developmental stages until a large body of mature tissue builds up, then a steady state will be maintained.

In earlier work, Ching (1973) reported that the seed ATP content determination during germination correlated well with the viability and the seedling size of ryegrass, rape and crimsom clover seeds, and subsequently Ching (1982) recommended a cautious approach in using seed ATP content to predict seed vigour and stand establishment in the field.

At the end of the second experiment in this project, it was decided to include a biochemical vigour test. As no report of any relationship between seed ATP content of peas and vigour and how it is affected by the mother plant nutrition had been found in the literature, an attempt was made to investigate this phenomenon.

In this experiment, just the levels of nitrogen supply significantly affected the seed ATP content (after 24 hours of imbibition in the dark at 20°C) at the 5 % significance level (Table 90). Incresing the level of nitrogen from N_1 (100 mg per plant) to N_2 (1000 mg per plant) decreased the seed ATP content by 35.5% (Figure 185). Increasing levels of phosphorus supply also had a similar effect but not significantly (Figure 185). Seed ATP content decreased by as much as 43.2%, when the phosphorus supply was increased from P_1 (25 mg per plant) to P_3 (500 mg per plant).

In contrast to Ching (1973), (working with Dixie crimson clover (*Trifol ium incarnatum* cv. Dixie), annual rye grass (*Lolium multi-*

florum L.) and common rape (*Brassica napus* L.)), the seed ATP content correlated negatively with seed size and seedling dry weight of peas as shown in Table 109.

Correlation Coefficient between seed ATP content and:					
Plant dry weight	Weight per seed	Seed N content	Seed P content	Seed K content	Seed Mg content
-.767**	-.624 NS	-.680 *	-.617 NS	.034 NS	-.671 *
G.T. % germination	G.T.% normal	G.T. seedling dry wt.	C.T. % germination	C.T. seedling dry wt.	Seed Conductivity
.159 NS	.412 NS	-.580 NS	.282 NS	-.380 NS	-.388 NS

Table 109. The correlation coefficient between seed ATP content and seed yield and quality assessment parameters.

Critical values of the correlation coefficient for specified levels of significance in a two-tailed test in Experiment 2, n = 8,

5% or *	1% or **	0.1% or ***
.6319	.6614	.8721

Seed ATP content of peas in this experiment was measured after 24 hours of imbibition. Further detailed work is necessary to determine the ATP content oscillation at close time intervals. 24 hours of imbibition will definitely start the germination bioactivities, but whether the ATP production and or production are in phase with the germination demand in pea seeds needs investigating. However, because of the limitations imposed at the time of the determination, the results will need to be repeated in order to be confirmed.

	Experiments	Seed size: mean seed weight	G.T. % germin-ation	G.T. % normal seedlings	G.T. % seedling dry wt.	Conductivity test	C.T. % germin-ation	C.T. seedling dry weight	Seed ATP content
Levels of nitrogen fertilizers	1	↑→↓	↓	N/E	↓→↑	N/E	↑	↑	-
	2	↑	↓	↓	↑	↑	↓	↓	↓
	3	↑	↓	N/E	N/E	↓	↓	N/E	-
	4	N/E	N/E	N/E	↑	↓	↓→↑	↓→↑	-
Level of phosphorus fertilizers	1	↓→↑	↑→↓	↓	↑	↓	↑→↓	↑	-
	2	↑→↓	↑→↓	↑→↓	↑→↓	↓→↑	↑→↓	↑→↓	↓→↑
	3	↑→↓	↓	N/E	↓	N/E	N/E	↑	-
	4	-	-	-	-	-	-	-	-
Levels of potassium fertilizers	1	↓→↑	N/E	↑→↓	↑→↓	↓→↑	↑→↓	N/E	-
	2	-	-	-	-	-	-	-	-
	3	↓→↑	↓→↑	N/E	↓→↑	↑	↓→↑	↑	-
	4	↑	↑→↓	↑→↓	↑→↓	N/E	↑	↑	-

Table 109. Summary of the effects of N, P and K nutrition supply in seeds from Experiments 1, 2, 3 and 4 on seed quality and seed vigour parameter.

↑ = increase; ↓ = decrease; N/E = not affected - not included as a variable in the experiment

From the summary in Table 109, and the previous discussion, regarding the effect of mother plant nutrition on seed quality parameters, the following conclusions can be drawn.

a) The increasing levels of nitrogen nutrition have increased seed size, and seedling dry weight in the germination test, decreased percentage germination, and the percentage of normal seedlings in the germination test, cold test, percentage germination and seedling dry weight and seed ATP content. Seed conductivity was decreased in two experiments, (2 and 3) increased in one (Experiment 1) and not affected in the first experiment.

b) The increasing levels of phosphorus nutrition have no consistent effect on any of the parameters. The increase in phosphorus supply has initially increased the effect and eventually decreased, the effect on seed size, germination test, percentage germination and seed ATP, whereas the converse was true for seedling dry weight in the germination test. However, increasing levels of phosphorus decreased seed leachate conductivity and increased cold test seedling dry weight.

c) The increasing levels of potassium had an inverse effect on seed size, seed conductivity and cold test seedling dry weight and its effect on the germination test, percentage germination, percentage normal seedlings and cold test percentage germination test was inconsistent in the experiments.

5.6 General Discussion

From the above results and discussion based on the present study, the following general points can be made in relation to the production of seeds of *Pisum sativum* c.v. Sprite.

1) The application of nitrogen nutrition to the mother plants grown under glasshouse conditions (Experiments 1, 2 and 4) significantly increased the plants' vegetative growth and parameters relating to seed yield, such as pod number, pod dry weight, seed number and seed dry weight per plant, whereas plants grown in the field (Experiment 3) did not respond significantly and only plant dry weight and seed dry weight were increased slightly. The difference in response to nitrogen supply in glasshouse and field experiments could be due to a) nitrogen availability and b) *Rhizobium leguminosorum* activity. In the glasshouse experiments the total nitrogen nutrition was in part supplied as a base dressing before sowing and part as liquid feed after seedling emergence throughout the growth of the plants. Loss from leaching was prevented. Whereas in the field experiment, the total nitrogen nutrition supply was incorporated in the soil before sowing. Due to exceptionally high rainfall during the early part of crop establishments, it is likely that some of the nitrogen may have been leached out before the plants were able to benefit from it. On the other hand, the growth medium used in the glasshouse experiments was relatively sterile and no nitrogen fixing bacteria *Rhizobium leguminosorum* were deliberately added, thus the plant relied completely and responded positively to the mineral nitrogen supply. In the case of the field experiment, the plants were able to perform this unique symbiotic activity which make them less dependent on the external

mineral supply. This was confirmed by the presence of root nodules observed after the end of the experiment. Therefore the levels applied to the field experiment were either too low to have any effect or the method of application needs further investigation in order to achieve similar effect to the glasshouse experiments. The relatively high rate of leaching under field conditions could imply that benefit could be obtained from relatively frequent top dressing or foliar applications. This overall response to nitrogen nutrition agrees with Browning's (1980)work on peas who also reported no significant effect of nitrogen on yield and quality in field experiments.

In the present study, increasing nitrogen supply increased seed N, Mg and Mn content and decreased seed P, Fe and Cu content in the glasshouse experiments. The nutrient content of the seeds from the field experiment were not affected significantly. Increasing nitrogen supply also increased seed size as determined by mean seed weight in the glasshouse experiments (1, 2 and 4), whereas decreased the percentage germination in the germination test in the same experiment. However, the effect of nitrogen nutrition on seed vigour as determined by the vigour tests was not consistent. For example, based on the result of the glasshouse experiment number 2, increasing nitrogen supply, increased plant dry weight, seed yield, seed N content and seed size, but it also increased the conductivity of seed leachates. The latter is a reflection of reduced seed vigour and was supported by the reduction of the germination percentage in the germination and the cold test. In addition, the percentage of normal seedlings, cold test seedling dry weight and seed ATP content were reduced. In this experiment, it could therefore be said that increasing nitrogen nutrition increased seed yield substantially at the expense of seed

quality. Whereas in the glasshouse experiments, 1 and 4, the increase in nitrogen nutrition supply not only increased plant growth and seed yield, but it also improved seed vigour, by having a reducing effect on seed leachates conductivity and increased the percentage germination and the seedling dry weight of the cold test. Increasing nitrogen supply did not have a significant effect on seed yield and quality in the field experiment.

2) The application of phosphorus nutrition to the mother plant grown under glasshouse conditions (Experiments 1, 2 and 4) significantly increased their vegetative growth and subsequent seed yield parameters, such as pod number, pod dry weight, seed number and seed dry weight per plant. Whereas plants grown in the field (Experiment 3) did not respond significantly to phosphorus levels. Increasing levels of phosphorus nutrition decreased seed N content in Experiments 1, 2 and 3 and increased seed P, K and Mg in Experiments 1 and 2. The effect on seed Mn, Fe and Cu were not consistent between the experiments. Results from Experiments 1, 2 and 3 indicate that increasing phosphorus nutrition improves seed quality and vigour, but only up to a certain level of phosphorus supply. There is an indication that above 500 mg of phosphorus per plant, there is either no effect on seed quality, or the positive effect is limited by the suitability of other factors such as nitrogen nutrition, soil pH, temperature and light. Thus increasing the levels of phosphorus initially increased seed size, percentage germination (as observed in the germination and the cold test) and seedling dry weight (as observed at the completion of the germination and the cold tests) and then decreased with higher levels of phosphorus. Increasing levels of

phosphorus had the converse effect on seed leachates conductivity. In Experiment 2, the seed leachates conductivity was initially decreased with increasing levels of phosphorus and then increased at the highest level of phosphorus supply. The seed leachates conductivity of the seeds from the field experiment was not significantly affected by increasing levels of phosphorus nutrition, their percentage germination and seedling dry weight at the completion of the germination test was reduced, but not significantly. In Experiment 2, the effect of phosphorus supply on seed ATP content followed the same trend as the seed leachates conductivity, in that there was an initial decrease followed by an eventual increase at the highest level of phosphorus.

3) The application of potassium nutrition to the mother plants grown under glasshouse conditions (Experiments 1, 2 and 4) had no significant effect on plant vegetative growth as determined by plant dry weight and only increased pod dry weight, seed number and seed dry weight in Experiment 4. The most important and consistent effect of potassium nutrition in Experiments 1 and 4 was the significant effect on the pod set as determined by the number of seeds per pod. Increasing nitrogen and phosphorus supply had mostly no effect on the number of seeds per pod and only in Experiment 4, the nitrogen levels, and in Experiment 2, the phosphorus levels reduced the number of seeds per pod. Increasing levels of potassium nutrition supply decreased seed N, P, Mn and Fe content in the glasshouse experiments, whereas it only increased seed K content in Experiment 4 and seed Cu content in Experiments 1, 3 and 4. The potassium supply had mostly no significant effect on seed nutrient content from the plants grown in the field. The effect of increasing levels of potassium nutrition on

seed quality and vigour is very inconsistent between the experiments. For example, the conductivity of seed leachates was increased in Experiment 3 and in Experiment 1, it initially decreased and then increased at the highest level of potassium, and was found to have not been affected in the fourth experiment, where potassium, was one of the major nutrient variables. There is also an indication that higher levels of potassium have an increasing effect on seed size and cold test seedling dry weight.

4) There was an interaction effect of NP, NK, PK and NPK on seed yield, quality and vigour parameters assessed in this study. Generally higher levels of nitrogen with medium levels of phosphorus gave increased germination and seedling dry weight and decreased seed conductivity.

5) There is no consistent correlation between seed chemical composition and seed yield, quality and vigour parameters. However there is an indication that seed size is positively and highly correlated with seed N, P and K content, whereas seed Fe and Cu content are negatively correlated. Seed size is also negatively correlated with seed leachates conductivity, meaning that smaller seeds contain less N, P and K and lose more of their contents by leaching during the conductivity test, than the larger seeds. Thus highlighting the importance of the adequate nutrient supply to the mother plant for production of larger high quality seeds. Seed size was positively correalted with the percentage germination in the germination and the cold test, as well as the seedling dry weight at the completion of the germination and the cold test. Seed leachates

conductivity is also negatively correlated with the percentage germination of the germination and the cold test, percentage of the normal seedlings and seedling dry weight of the germination and the cold test.

6. CONCLUSION

6.1 General Conclusion

In the greenhouse experiments, increasing the levels of nitrogen supplied to peas, when nodulation was absent, resulted in increase in seed yield, seed nitrogen content and hence protein and seed size. In two out of the three glasshouse experiments increased nitrogen supply improved seed vigour as determined by the lower seed leachates conductivity and higher germination percentage and seedling dry weight of the germination test and the cold test. The effect of phosphorus nutrition on seed yield was not as large as nitrogen, but it improved seed quality and vigour in all the glasshouse experiments. There is an indication that an optimum phosphorus level of 500 mg per plant exists for pea plants grown in containers, above which where is a negative effect. The interaction effect of nitrogen and phosphorus on seed quality and vigour is more significant than the effect of the individual elements.

Fertilizer application to a seed crop grown in the field failed to produce differences in seed yield, seed chemical composition or seed vigour.

Further work on methods of fertilizer application and split application on the crops grown in the field is required to verify the overall effect of the glasshouse experiments in the field. It is also worth investigating the performance of mother plants and the subsequent effect on seed quality when grown in glasshouses in growth media which include the nitrogen fixing bacteria *Rhizobium leguminosorum*.

Further work is also needed on establishing the effect of mother plant nutrition on the chemical composition of the seed with particular reference to cell membrane structure and functioning, as

well as further development of the biochemical vigour tests such as the seed ATP content in peas.

Further investigations should also be made into the effects of mother plant nutrition on the chemical composition of seed leachates with the aim of establishing an easy analysis which would be an accurate indicator of potential seed vigour.

7. REFERENCES

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